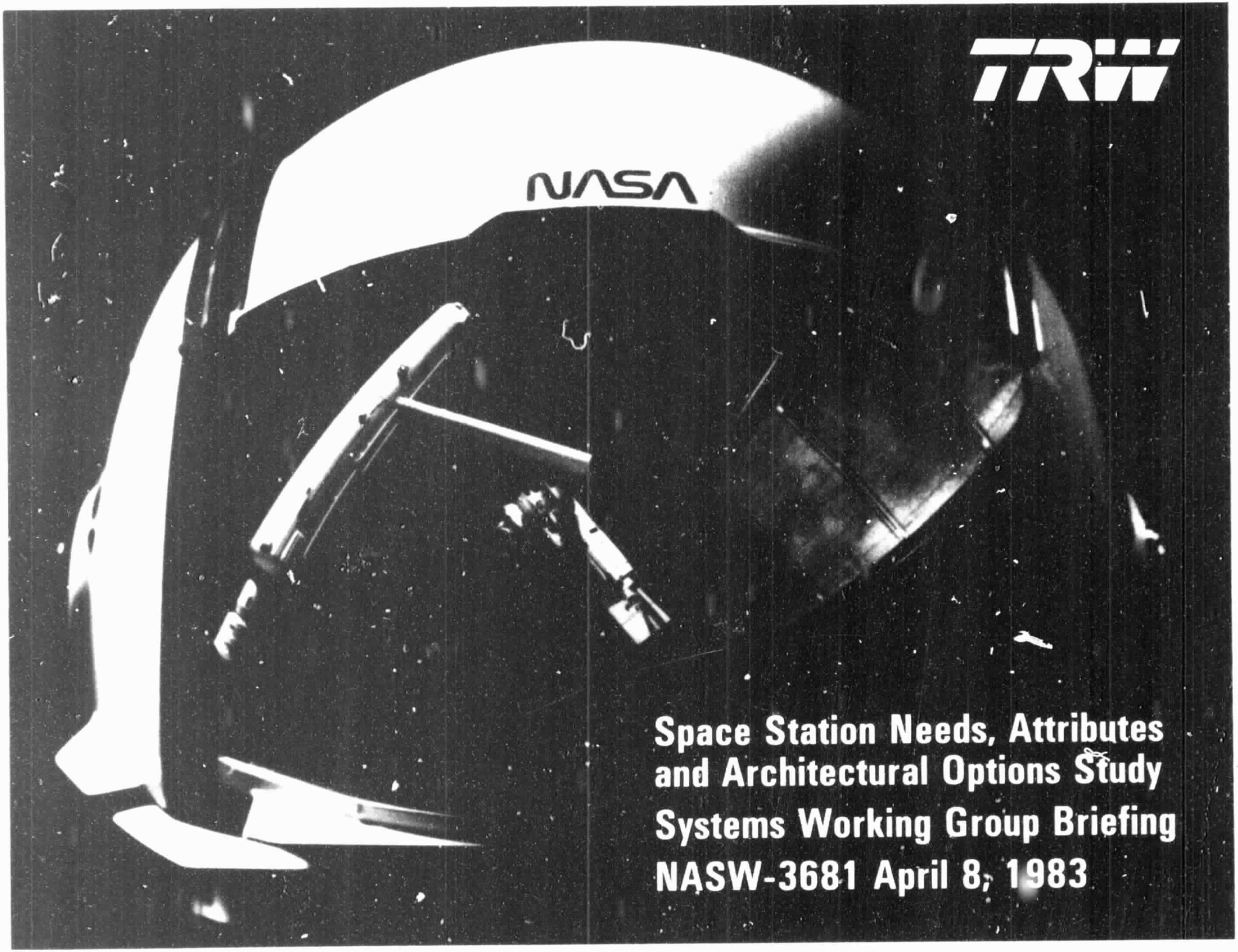
TRW

(NASA-CR-172952) SPACE STATION NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS STUDY SYSTEM WORKING GROUP BRIEFING Final Report (TRW Space Technology Labs.) 155 p HC A08/MF A01 CSCL 22B G3/18 N83-31719 Unclas 15005

Space Station Needs, Attributes and Architectural Options Study

Systems Working Group Briefing

NASW-3681 April 8, 1983


TRW
NASA
Space Station Needs, Attributes
and Architectural Options Study
Systems Working Group Briefing
NASW-3681 April 8, 1983

AGENDA

PRECEDING PAGE BLANK NOT FILMED

- ASSUMPTIONS
- TRADES
- MANIFESTING
- BUILDUP
- CHARACTERISTICS
- GROUND OPERATIONS
- OTHER TOPICS

PRECEDING PAGE BLANK NOT FILMED

ASSUMPTIONS

ASSUMPTIONS FOR STS CAPABILITIES

This chart presents the STS capabilities assumptions on which the SS overall architecture is based. The STS is the major vehicle for transporting the modules to orbit, for assembling the modules to each other, for transporting/rescuing the crew, for resupplying the SS and for lifting payloads to orbit.

The projected payload lift and landing weight capabilities are based on the NASA briefing of September 1982. The other items are existing STS capabilities.

ASSUMPTIONS FOR STS CAPABILITIES

- PAYLOAD CAPABILITY
  - 28.5° X 150 NM — 72,000 LBS
  - 97.5° X 150 NM — 32,000 LBS
- LIFE SUPPORT SYSTEMS — 4 MEN, 7 DAYS
- LANDING WEIGHT CAPABILITY — 43,000 LBS
- ONE STANDARD RMS IS AVAILABLE
- OMS KIT NOT REQUIRED
- CAPABILITY OF TRANSPORTING SPACE STATION CREW (UP TO 5 MEN) TO/FROM ORBIT IS AVAILABLE
- CAPABILITY OF RESCUING SPACE STATION CREW (UP TO 10 MEN) IS AVAILABLE

SS SAFETY ASSUMPTIONS

Crew safety is based on redundancy in all aspects of life sustaining equipment and the means of using them.

The structure of the Habitable Modules is intended to provide protection from particles of reasonable size. Major failures are provided for by redundant Habitable Modules.

It is assumed that Orbiter rescue is available only at sufficient notice and this contingency is provided against by installing 21 days emergency supplies in all Habitable Modules.

In the event of a predictable solar flare the crew will be evacuated by the Orbiter.

SS SAFETY ASSUMPTIONS

- LIFE SUSTAINING CAPABILITIES SHALL
  - ALLOW SINGLE FAILURES WITHOUT EFFECT
  - ALLOW DUAL FAILURES IN A CREW-SAFE MANNER
- THERE SHALL BE AT LEAST TWO:
  - HABITABLE AREAS
  - AIRLOCKS
  - PORTS FOR ORBITER BERTHING
  - EGRESS PATHS FROM EACH HABITABLE AREA
- HABITABLE AREAS SHALL BE AS INDEPENDENT OF EACH OTHER AS POSSIBLE
- PROTECTION SHALL BE PROVIDED FOR
  - NATURAL RADIATION
  - MICROMETEOROIDS
  - SPACE DEBRIS
- ORBITER RESCUE IS ASSUMED
- AN AMBULANCE REENTRY VEHICLE MAY BE DESIRABLE

SS CONFIGURATION ASSUMPTIONS

The SS is an evolving modular system based on the use of the Orbiter for transportation, assembly and supply in LEO at both low and high inclinations. Crew safety is obtained by redundancy/self sufficiency in the HM's and by multiple escape paths from one HM to another. In addition to servicing satellites, the SS is equipped to carry payloads of its own, both externally on the Resource Module and on the main body, and internally in the Habitable Modules.

As the SS grows, facilities are added for OTVs, TMS repair and refueling. Growth is not limited to increase in size, but technological advances can also be incorporated into the SS as they occur.

SS CONFIGURATION ASSUMPTIONS

- CONCEPTUAL DESIGN BASED ON EVOLVING MODULAR DESIGN
- ALL MODULES USEABLE AT EACH STAGE OF EVOLUTION
- ALL MODULES FIT WITHIN ORBITER BAY
- EACH HABITABLE MODULE SHALL BE LARGELY SELF-SUFFICIENT
- ALL MANNED MODULES SHALL BE INTERCONNECTED
- RESOURCE MODULE SIZED TO PROVIDE MODULAR GROWTH OF SS RESOURCES BY ADDING DUPLICATE RM'S OR PORTIONS OF RM'S
- RESOURCE MODULE CAN SUPPORT SEVERAL EXTERNALLY-MOUNTED PAYLOADS WHILE ATTACHED TO SS
- MODULE SIZES CONSISTENT WITH REDUCED CARGO MASS CAPABILITY OF THE ORBITER FOR LAUNCHES INTO POLAR ORBIT
- SUITABLE PORTS PROVIDED ON THE SS MAIN BODY FOR EXTERNAL PAYLOAD ATTACHMENT
- SUITABLE VIEWING FROM WITHIN SS OF ALL EXTERNAL CRITICAL ITEMS

SS CONFIGURATION ASSUMPTIONS (CONT.)

- AREAS AND FACILITIES SHALL BE PROVIDED FOR:
  - LARGE STRUCTURE CONSTRUCTION
  - SPACECRAFT, PAYLOAD, OTV AND TMS STORAGE, REPAIR, SERVICING, MAINTENANCE AND REFUELING
  - SPACECRAFT/PAYLOAD ASSEMBLY, STAGING AND CHECKOUT
- SS SHALL BE CONSTRUCTABLE AND RECONFIGURABLE, THROUGHOUT ITS EVOLUTION, USING ONLY THE MANIPULATORS ON THE ORBITER AND/OR ON THE SS ITSELF
- TECHNOLOGY OF ALL SUBSYSTEMS CAN BE UPGRADED ON-ORBIT
- SS CONFIGURATION AND MODULES SHALL BE SUCH THAT EACH STAGE OF INITIAL ESTABLISHMENT, GROWTH, OR ADDITION OF CAPABILITIES CAN BE ACHIEVED BY THE MINIMAL NUMBER OF ORBITER FLIGHTS

SS RESUPPLY CONCEPT

Resupply is based on the use of Logistics Modules transported by the Orbiter, then berthed to the SS where they remain until exchanged for fresh Logistics Modules on the next resupply flight.

The Logistics Modules carry up to the SS all consumables, small repair parts, supplies etc. and return to Earth with such items as trash and used components. The size of the Logistics Modules depends on the orbit inclination (Orbiter lift capability), resupply cycle and other variables.

SS RESUPPLY CONCEPT

- LOGISTIC MODULES SUPPLY ALL CONSUMABLES NECESSARY FOR NORMAL SS OPERATION
- THE LOGISTIC MODULE RESUPPLY CYCLE IS DEPENDENT UPON THE ORBIT AND THE SS CREW SIZE
- EMERGENCY SUPPPLIES FOR A MINIMUM OF 21 DAYS SHALL BE STORED IN EACH HABITABLE AREA
- NO GREATER THAN HALF OF THE CREW WILL BE CHANGED OUT DURING EACH ORBITER VISIT
- SUFFICIENT PROPELLANT WILL BE STORED TO MAINTAIN THE SS REQUIREMENTS FOR 6 MONTHS WITHOUT RESUPPLY

DATA MANAGEMENT REQUIREMENTS

Preliminary and approximate space station data management requirements are derived using the integrated mission requirements and the space station study scenario assumptions. These requirements are given in the chart according to the format requested by B. Pritchard in a February 1983 letter to the space station study managers. It should be emphasized that these data are very preliminary and require additional trade analysis prior to further refinement. One central issue that requires resolution involves the question of ground vs. space station-based computing capability. Many of the requirements parameters are directly affected including: real time coverage (R/T TT&C), on board computing, SS-ground computing, sequence storage, and manned control.

DATA MANAGEMENT REQUIREMENTS (1995)

PARAMETER	FACILITY/INCLINATION			
	SS/28.5°	SP/28.5°	SS/97°	SP/97°
1. PER ORBIT DATA VOL, GB	194	8	875	875
2. R/T TT&C, PERCENT FACILITY CONTROL PAYLOAD CONTROL	~0 0 → 100	~0 0 → 100	~0 0 → 100	~0 0 → 100
3. ON BOARD COMPUTING FACILITY CONTROL PAYLOAD SUPPORT	√ (MANNED LAB)	√	√ (MANNED LAB)	√
4. SS-GROUND COMPUTING TRAFFIC, MBPS	36	1.5	162	162
5. SEQUENCE STORAGE	TBS	TBS	TBS	TBS
6. MANNED CONTROL	ON BOARD, R/T TT&C	R/T TT&C	ON BOARD, R/T TT&C	R/T TT&C
7. TELECONFERENCING SUPPORT	VOICE, MULITCHANNEL TV	NA	VOICE, MULTICHANNEL TV	NA
8. ANALOG DATA	ON BOARD A/D	ON BOARD A/D	ON BOARD A/D	ON BOARD A/D
9. SECURITY NEEDS, MBPS DoD COMMERCIAL	20 MINIMAL	NONE	72 45	72 45

TRADES

Orbiter Improvements. Thrust augmentation is advantageous because it bestows greater lift capability and therefore reduces the number of Orbiter flights required. The proposed landing gear improvements are required to increase the abort landing load capability. The OMS kits are not as useful as the Orbiter tank kits proposed by TRW. The docking system is necessary for Orbiter operations in assembling the SS and for transferring crew and supplies.

Orbiter Tank Kits. OMS kits are not effective as a means of increasing Orbiter payload. An Orbiter Tank Module (OTM) sized for 50,000 lbs of cryogens is 14.5' dia. x 24' long and weighs 5,000 lbs dry including pumps and insulation. It is used to "ballast up" payloads with cryogenic fuel loads where this is appropriate and also to help with CG location. It could be used as a tank into which ET propellants would be scavenged.

RMS Type. The existing RMS is a versatile system which can be equipped with many tools and end effectors. It has the ability to reach into nearly every corner of the payload bay and is capable of handling the largest and heaviest payloads/modules the Orbiter can lift.

RMS Number. While the SS and the Orbiter are docked to each other there will be two RMS's available for cargo transfer or other operations.

ET Use. The ET is not suitable as a Habitable Module because of its structure (micro-meteoroid protection) and the difficulty of outfitting it in space with the necessary systems. To convert the ET into an unpressurized Hangar is more reasonable, although it would require considerable modification (e.g., remove one end of the LH_2 tank). Some of the interior equipment might be installed before launch.

ET Fuel Scavenging. Taking the ET's to the SS creates the problem of disposition of the ET's. Maintaining them in orbit requires up to 5,000 lb of fuel/year for altitude maintenance per ET. The maximum fuel recovery of 6,000 lb probably does not justify scavenging because of the cost involved.

ACC Use. If the aft cargo carrier were employed the useful payload would be reduced accordingly. There is no reason to carry something in the ACC if it will fit into the Orbiter Bay, as do all the conceptual modules.

STS TRADE SUMMARY

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
ORBITER IMPROVEMENTS	THRUST AUGMENTATION LANDING GEAR AUGMENTATION DOCKING MODULE OMS KIT	INCREASED LIFT CAPABILITY, EFFECTIVITY, CREW TRANSFER NEED
ORBITER TANK KITS	ORBITER BAY (REMOVABLE) NONE OMS KITS	ORBITER MANIFEST EFFICIENCY, UTILITY
RMS TYPE	EXISTING MODIFIED NEW	COST, NEEDS
RMS NUMBER	ONE TWO	COST, NEED
ET USE	NONE HANGAR HABITABLE AREA	COST, PRACTICALITY
ET FUEL SCAVENGING	NONE ET INTO ORBIT INTO ORBITER	COST, FUEL RECOVERABLE
AFT CARGO CARRIER USE	NONE FUEL TANKS LARGE DIA MODULES	LOSS OF LIFT CAPABILITY, LACK OF NEED

SPACE STATION TRADE SUMMARY

Altitude Strategy

For the early (small) or interim (medium-sized) SS, the best strategy is to operate the SS at a low altitude ($\sim$ 160 nmi), where the Orbiter capability is maximized. For the large SS in 2000, the best solution is to use TMS transfer of payload from low Orbiter to higher ($\sim$ 200 nmi) SS.

Disturbance Torque Accommodation

The configuration and orientation should be chosen to minimize torques. A combination of CMG's for momentum storage and magnetic and propellant unloading should be the best (least cost) solution.

Power Source

Fuel cells would consume 63,050 lbs of cryogen to provide an average of 35 kW of power for 90 days (based on the Orbiter fuel cells). They would also produce 62,000 lbs of water, most of which is not needed. Solar arrays are an established technology. The big advantage is the production of power over many years without resupply. Nuclear power is a future possibility.

Energy Storage

Nickel-cadmium or nickel-hydrogen batteries are a conventional method of storing electrical energy. They suffer from the disadvantage of only a 25%-30% depth of discharge to maintain a reasonable length of life. Energy wheels convert electrical energy to kinetic energy and back again. They can pose a safety problem if run at very high speeds. Reversible fuel cells are a strong candidate for the future.

Propellant

Bi-propellant has the best cost/performance ratio and avoids the problems of storing cryogens (insulation, boil off). The system might be converted to cryogenic in the future.

Near Free Flyer Orbit Control

Tethering of FF's to the SS (whether loose or tight) presents problems which are not as yet fully understood, and techniques which are yet to be demonstrated. Co-orbiting FFs are more state of the art and present less risk.

Free Flyer Rendezvous

Moving the Space Station to the Free Flyer(s) would consume large amounts of fuel. Moving the FF's to the SS under their own power consumes less fuel. If time is not critical they may be "drifted" to the SS. The TMS can be used to capture the FF and tow it to the SS.

SPACE STATION TRADE SUMMARY

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
ALTITUDE STRATEGY	SS HIGH, STS HIGH SS LOW, STS LOW SS HIGH TO LOW, STS LOW SS HIGH, STS LOW, TMS TRANSFER	FUEL CONSUMPTION, COST, LOSS OF ORBITER CAPABILITY
DISTURBANCE TORQUE ACCOMMODATION	PROPULSION ONLY CMG's – PROP. UNLOADING CMG's – PROP/MAGNETIC UNLOADING MINIMIZE/BALANCE TORQUES	ADEQUACY, COST, PROPELLANT RESUPPLY
POWER SOURCE	LIGHT WEIGHT SOLAR ARRAY CONCENTRATOR SOLAR ARRAY NUCLEAR FUEL CELLS	COST, SAFETY, WEIGHT TO ORBIT
ENERGY STORAGE	BATTERIES REVERSIBLE FUEL CELLS ENERGY WHEELS	SAFETY, EXISTING TECHNOLOGY, RISK
PROPELLANT	MONO-PROPELLANT BI-PROPELLANT CRYOGENIC CRYO BOIL-OFF	COST/PERFORMANCE RATIO, RISK
NEAR FF ORBIT CONTROL	CO-ORBITING TIGHT TETHERING LOOSE TETHERING	FEASIBILITY, RISK
FF RENDEZVOUS	MOVE SS MOVE FF USE TMS	FUEL/CREW EFFICIENCY FF CAPABILITY, MISSION NEEDS

Habitable Module Transportation. The HM's are designed and sized for transportation inside the Orbiter to make the best use of the existing capabilities of the STS with regard to cost, risk and need. Using the ACC always reduces lift capability and the ET is not suitable for adaptation as an HM.

Hangar. The need for a Hangar is not clearly defined. In many ways the slight advantages that accrue from having a Hangar are not worth the cost of developing, fabricating and transporting such a large item. Astronauts will necessarily be working in unprotected/unpressurized areas from time to time and will be exposed to micro-meteroids. An unpressurized shelter is a possibility for the growth version of the SS.

Payload Pointing. It is more practical to gimbal payloads to point in the correct direction. Individual payloads will have many different requirements for accuracy, direction of pointing, tracking of targets etc. It is not reasonable to design a SS which is dynamically and thermally rigid enough to meet requirements which may not be defined for many years to come.

Fuel Transfer. Retanking would require multiple tanks at the SS to maintain 150,000 lbs of cryogens, thereby causing higher structural weight and multiple docking interfaces. Pumping can be used in conjunction with the Orbiter Tank Modules for fuel transfer.

Airlock Location. Use of the STS airlock module external to the HM's provides lowest cost, least loss of volume and maximum flexibility of location.

RMS Type and Number. It is believed that one existing-type RMS mounted on a trolley/rail system will be capable of handling the tasks of a Space Station when used in conjunction with the RMS of a docked Orbiter.

SPACE STATION TRADE SUMMARY (CONTINUED)

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
HABITABLE MODULE TRANSPORTATION	USE ET AFT CARGO CARRIER INSIDE ORBITER	EXISTING CAPABILITY, COST, RISK, NEED
HANGAR	NONE SHELTER PRESSURIZED	COST, NEED
PAYLOAD POINTING	POINT SS ACCURATELY GIMBAL P/L's ANGULAR AND LINEAR ISOLATION	COST, PRACTICALITY, ACCURACY DIFFICULTY OF PRECISE SS POINTING
FUEL TRANSFER (CRYOGENS)	RE-TANK PUMP	COST, EASE OF OPERATIONS, RELIABILITY
AIRLOCK LOCATION	INSIDE OUTSIDE	COST, SPACE, SAFETY, FLEXIBILITY
RMS TYPE	EXISTING MODIFIED LENGTH MODIFIED ANGLES NEW	COST, NEEDS
RMS NUMBER	ONE TWO	COST, NEEDS REDUNDANCY

Manipulator Mobility. For the initial SS the manipulator (RMS) is not required to possess much mobility; two or three attach ports at strategic locations will provide the necessary reach. When a larger SS is established, a rail/trolley systems is needed to move the manipulator about the SS and to transport OTV's/satellites from the assembly area to the hangar.

Docking/Berthing. Berthing, using the Orbiter RMS to move the Orbiter and mating vehicle together at a closely controlled rate, is safer than flying the Orbiter directly into a docking interface. For known berthing conditions the motion of the RMS can be controlled by the on-board RMS computer.

Internal HM Architecture. Configuring the HM with a longitudinal floor provides more usable space than dividing it into a larger number of small rooms by multiple transverse floor. Mobility is improved and claustrophobic conditions reduced.

Orientation. The factors influencing the choice of SS orientation are aerodrag (presenting the smallest frontal area to the velocity vector), minimizing gravity gradient torques (having the principle axis aligned with the gravity vector), payload pointing and viewing, and alignment of the solar arrays and radiators relative to the sun line.

Disposal. At some time when the SS has outlived its usefulness the question of its disposal will arise. Unless an unsuspected cheap source of energy becomes available to boost the SS out of earth orbit, dumping it in the ocean (after removing contaminant sources) is selected. Attempting to dismantle the SS and returning it to earth is a hazardous and expensive proposition.

Artificial Gravity. The ability of astronauts to perform in zero gravity is well established although long term effects are not completely understood. The lack of a feasible method of creating a gravity field in anything but a restricted area of the SS guides the initial choice towards "no artificial gravity." A centrifuge can be added for experimental/observational work on small mammals and possibly humans.

Space Suit/EMU Improvements. Improvements to the space suit/EMU are required to enhance the EVA capabilities which will be needed for satellite repair, maintenance and servicing. Astronauts will be spending many hours in EVA and improved safety, mobility and elimination of pre-breathing time will contribute to the efficiency of the SS.

SPACE STATION TRADE SUMMARY (CONTINUED)

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
MANIPULATOR MOBILITY	RAIL/TROLLEY MULTIPLE ATTACH PORTS	SYSTEM GROWTH, FLEXIBILITY
DOCKING/BERTHING	DOCKING BERTHING	SAFETY, COMPLEXITY
INTERNAL HM ARCHITECTURE	LONGITUDINAL FLOOR LATERAL FLOORS	BEST USE OF SPACE, PSYCHOLOGICAL EFFECTS
ORIENTATION	S/A AXIS – PSL, X – LV S/A AXIS – PSL, X – INERTIAL S/A AXIS – POP, X – LV	SOLAR ARRAY EFFICIENCY, MINIMUM AERO DRAG
DISPOSAL	BOOST TO HIGHER ORBIT RETURN – SALVAGE DEBOOST	COST, SAFETY
ARTIFICIAL GRAVITY	CENTRIFUGE – LARGE CENTRIFUGE – SMALL ROTATING MODULE OTHER NONE	COST, FEASIBILITY
SPACE SUIT/EMU IMPROVEMENTS	8 PSI, REGENERABLE THERMAL REGENERABLE NO CHANGE	SAFETY, CREW TIME COST, RESUPPLY

SPACE STATION TRADE SUMMARY (Continued)

Communications Relay. The TDRSS was selected for initial relay communications since this system will be in place and operational into the 1990's. The S/K band services provided by TDRSS can accommodate the planned needs of the SS. Future systems such as 30/20 GHz and/or lasers should be considered for increased bandwidth and privacy.

Data Centralization. A partially centralized data system leading ultimately to a fully decentralized system was found to have the growth potential when compared to a fully centralized configuration.

Thermal Centralization. A hybrid system wherein the main modules each have a thermal control system with the capability of handling some payloads offers the advantages of redundancy and flexibility of operation. Other payloads with high thermal loads may be required to provide their own control system.

Life Support Centralization. A decentralized system with at least two separate and independent life sustaining modules offers the best approach to crew safety. Small subsidiary modules can be parasitic on larger modules.

Life Support System, H_2O Reclamation and Air Purification. A closed loop system is best for reducing the cost of logistics/resupply which is a major item in overall program costs. The effects of reasonable comfort/convenience for a crew in a strange environment for several months should not be overlooked.

Crew Hazard Survival. Crew hazards are solar flares, loss of life support system and injury/illness of individual crewman. All of these hazards can be overcome by a judicious blend of SS equipment redundancy and evacuation planning. An ambulance may be considered for medical emergencies.

SPACE STATION TRADE SUMMARY (CONTINUED)

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
COMMUNICATIONS RELAY	TDRSS 30/20 GHz LASER COMM	COST, EXISTING SYSTEM, NEED
DATA CENTRALIZATION	CENTRALIZED PARTIALLY CENTRALIZED DE-CENTRALIZED	COST, GROWTH, REDUNDANCY
THERMAL CENTRALIZATION	FULLY CENTRALIZED PARTIALLY CENTRALIZED	COST, AND PRACTICALITY, REDUNDANCY
LIFE SUPPORT SYSTEM CENTRALIZATION	CENTRALIZED DE-CENTRALIZED	SAFETY, REDUNDANCY, GROWTH
LIFE SUPPORT SYSTEM H_2O RECLAMATION	OPEN CYCLE PARTIALLY CLOSED FULLY CLOSED	RESUPPLY COST, LONG TERM CONVENIENCE, AND COMFORT
LIFE SUPPORT SYSTEM AIR PURIFICATION	OPEN CYCLE PARTIALLY CLOSED FULLY CLOSED	RESUPPLY COST, LONG TERM CONVENIENCE, AND COMFORT
CREW HAZARD SURVIVAL	DEDICATED SAFE HAVEN MULTIPLE HABITABILITY SPACES ESCAPE MODULE (LIFE BOAT) EMERGENCY RESCUE MODULE (AMBULANCE) ORBITER RESCUE	COST VS. SAFETY

OTV TRADE SUMMARY

Reusability. A switch from an expendable OTV to a reusable OTV should be made when the SS becomes operational. Reusable OTV's are cost effective in several ways:

(1) Saves the expense of a new OTV for each mission
(2) Structurally lighter, saves fuel and money
(3) Payloads in GEO are recoverable
(4) Saves the cost of lifting an OTV to LEO for each mission
(5) OTV fuel can often be lifted to LEO SS storage as "make up ballast" for small payloads in the Orbiter

Propellant. Cryogenic fuel is preferred for its higher I_{SP} which makes it weignt and cost effective

Propellant Resupply. The most cost-and weight-effective approach is to refuel at the SS using a central cryogen tank module with sufficient capacity to refuel several OTV missions.

Modularity. The ROTV should be modular to facilitate maintenance at the LEO SS and to accommodate payloads of varying weights by changing tank size.

Recovery. Trade studies conducted by TRW indicate that the fixed aerobrake concept is preferred from a cost standpoint.

Maneuvers. A perigee-only OTV is not cost or weight effective.

GEO Operations. A TMS based at the LEO SS but carried by the ROTV as required, provides the best method of servicing/recovering satellites in GEO. It avoids duplication by the ROTV, of functions/services already provided by the TMS.

Size. A modular ROTV which can be adapted over the range of 18-24 Klb for payloads is the preferred choice.

OTV TRADE SUMMARY

TRADE	CANDIDATES (INITIAL SELECTION / GROWTH SELECTION)	SELECTION RATIONALE
RE-USABILITY	EXPENDABLE RE-USABLE	COST, GEO SERVICING
PROPELLANT	SOLIDS BI-PROPELLANT CRYOGENIC	COST, WEIGHT
PROPELLANT RESUPPLY	RE-FUEL FROM SS EXCHANGE TANKAGE RETURN OTV	COST, WEIGHT, MISSION FLEXIBILITY
MODULARITY	MODULAR MONOLITHIC	COST, MISSION FLEXIBILITY, WEIGHT
RECOVERY	ALL PROPULSIVE AEROBRAKING—FIXED AEROBRAKING—BALLUTE	COST, WEIGHT, REUSEABILITY
MANEUVERS	PERIGEE ONLY + P/L AKM PERIGEE AND APOGEE	COST, WEIGHT
GEO OPERATIONS	NONE OTV TMS CARRIED WITH OTV	COST, WEIGHT, MISSION FLEXIBILITY
SIZE	6 KLb P/L 12 KLb P/L 18–24 KLb P/L MODULAR	COST, WEIGHT

TMS TRADE SUMMARY

Basing

With the TMS based at the Orbiter it would consume Orbiter weight/volume for every launch and would be subjected to many launch environments (vibration etc.). Although maintenance/reconfiguration of the TMS would be easier on the ground than at the SS it could be achieved only at the loss of the availability of the TMS for emergency/standard operations.

Propellant

Bi-propellant is first in cost/performance ratio. It might possibly be advantageous to switch to cryogenic propellants at some time in the future.

Sizing

The TMS is sized to fit into the Orbiter Bay and occupy the minimum length. It must also carry the equipment for performing the tasks assigned to it: capture, service, refuel satellites; docking and interface provisions for Orbiter, Space Station and satellites; power, avionics; LEO, GEO operations with extra tanks.

Control Base

The control base cannot be the Orbiter at all times, because much of the time the Orbiter is not on-orbit. For operations remote from the SS the control base should be the ground to relieve the crew of this duty. For operations near the SS the control base should be in the SS. This is especially so when docking/collision avoidance is required.

Fleet Size

For reasons of redundancy, more than one TMS is needed, and for economic reasons the number should be limited. If two TMS' is the minimum number, one can be configured for nearby (LEO) work and the other for distant (GEO) work. In the event of a breakdown of one TMS the other can be reconfigured in a reasonable amount of time even at the SS. There is also the question of providing a berth for each TMS at the SS without interfering with other station functions. For these reasons the fleet size should be set at two TMS' per SS.

TMS TRADE SUMMARY

TRADE	CANDIDATES ($\boxed{\text{INITIAL SELECTION}}$ / GROWTH SELECTION)	SELECTION RATIONALE
BASING	STS $\boxed{\text{SS}}$ SPACE	ORBITER LAUNCH COST, AVAILABILITY ON ORBIT
PROPELLANT	MONO-PROPELLANT $\boxed{\text{BI-PROPELLANT}}$ CRYOGENIC	COST/PERFORMANCE RATIO
SIZING	SMALL $\boxed{\text{MEDIUM}}$ LARGE	15 FT DIA. x 3 FT LONG. MEETS REQUIREMENTS
CONTROL BASE	$\boxed{\text{GROUND}}$ STS $\boxed{\text{SS}}$	COST, OPERATIONS CONSIDERATIONS
FLEET SIZE	ONE $\boxed{\text{FEW}}$ MORE	TWO PER SS COST, REDUNDANCY, NUMBER AND TYPE OF MISSIONS TO BE PERFORMED

MANIFESTING

SPACE STATION ARCHITECTURE SCENARIOS

Six different candidate scenarios were examined. All had free-flying spacecraft, small unmanned platforms, TMS and OTV's in common.

Scenario 0 is the baseline. This assumes neither SS or SP. It is what would/could be done without those elements. Scenario 1 adds Space Platforms. Scenario 2 has Space Stations, but no Space Platforms. Scenario 3 has an SS at LEO and one or more SP's at PEO.

Scenario 4 has SS's at LEO and PEO and an SP at LEO. Scenario 5 is like Scenario 4, except that an extended-stay Orbiter is used as part of the initial SS.

Space Station Architecture Scenarios

SCENARIO	SPACE PLATFORM		SPACE STATION	
	LEO*	PEO	LEO	PEO
0				
1	X	X		
2			X	X
3		X	X	
4	X		X	X
5**	X		X	X

*LEO — LOW INCLINATION (28.5°) LOW EARTH ORBIT
PEO — POLAR (97°) LOW EARTH ORBIT

**USES STS AS PART OF INITIAL SS

ALL SCENARIOS INCLUDE FREE FLIERS, SMALL UNMANNED PLATFORMS, TMS, OTV'S

SAMPLE
ORBITER MANIFESTING - SS STUDIES

This chart is an example of the manifesting of payloads and space station support modules into the Orbiter for launch. The chart provides the number and types of payloads including their weight and length for both launch and landing. In addition, the flight number, date of launch and destination (orbit) are also shown. This type of data was generated for each payload in the TRW Mission Model from 1990 to 2000 and for each of the six scenarios.

SAMPLE
ORBITER MANIFESTING – SS STUDIES

TRW

FLT. NO. 1
LAUNCH E/W (E circled)
DATE 1/95
ORBIT 28.5°

UP PAYLOAD	UP WT.	UP LGTH.	DOWN PAYLOAD	DOWN WT.	DOWN LGTH.
ASE	8	8	ASE	8	8
LM	41.6	26	RBM (2)	2	10
RBM (2)	9.4	10	CREW (4)	0.8	–
CREW (4)	0.8	–	CRE	6.8	11
TOTAL	59.8	44	TOTAL	17.6	29

FLT. NO. 2
LAUNCH E/W (E circled)
DATE 1/95
ORBIT 28.5°

UP PAYLOAD	UP WT.	UP LGTH.	DOWN PAYLOAD	DOWN WT.	DOWN LGTH.
ASE	8	8	ASE	8	8
CCS C1-2	10	20			
OTV	37	23			
TOTAL	55	51	TOTAL	8	8

FLT. NO. 3
LAUNCH E/W (W circled)
DATE 1/95
ORBIT 97°

UP PAYLOAD	UP WT.	UP LGTH.	DOWN PAYLOAD	DOWN WT.	DOWN LGTH.
ASE	8	8	ASE	8	8
ESRM	5.5	10	STP-VLS	5.5	13
STP-VLS	5.5	13	ME	2.6	7
RSS	8.8	14	CREW (2)	0.4	–
CREW (2)	0.4	–			
TOTAL	26.2	45	TOTAL	16.5	28

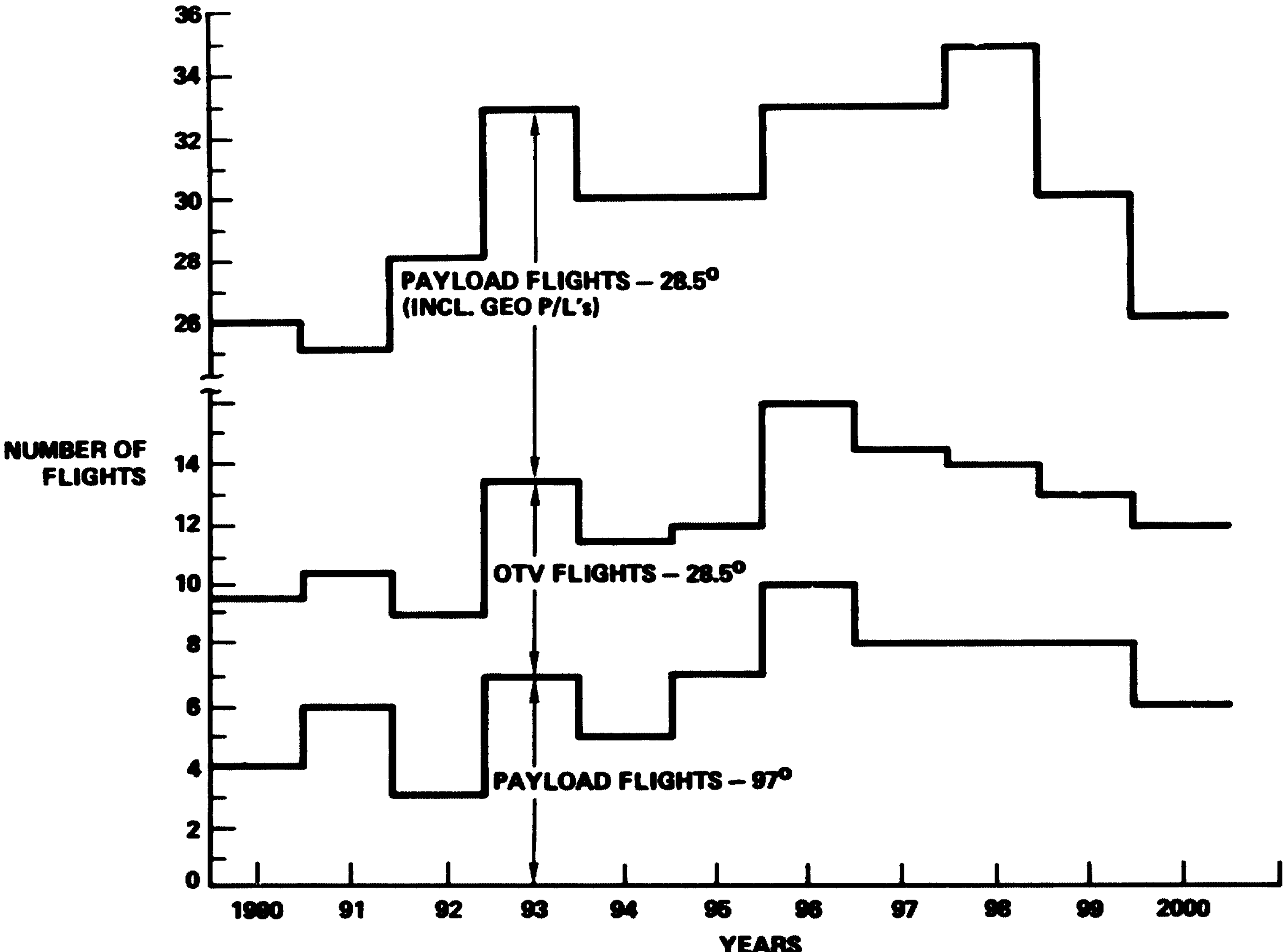
ORBITER FLIGHTS

SCENARIO NUMBER 0

A complete manifesting of all payloads for each Orbiter flight was conducted using the TRW generated mission model. Scenario 0 assumed no space station or space platform.

The attached figure indicates the cumulative number of Orbiter flights required per year for the 97° and 28.5° orbits in order to launch the specified Mission Model payloads in the required year. Included in the figure is the equivalent number of OTV flights per year to support the Geosynchronous orbit payloads.

ORBITER FLIGHTS
SCENARIO NUMBER 0



ORBITER FLIGHTS

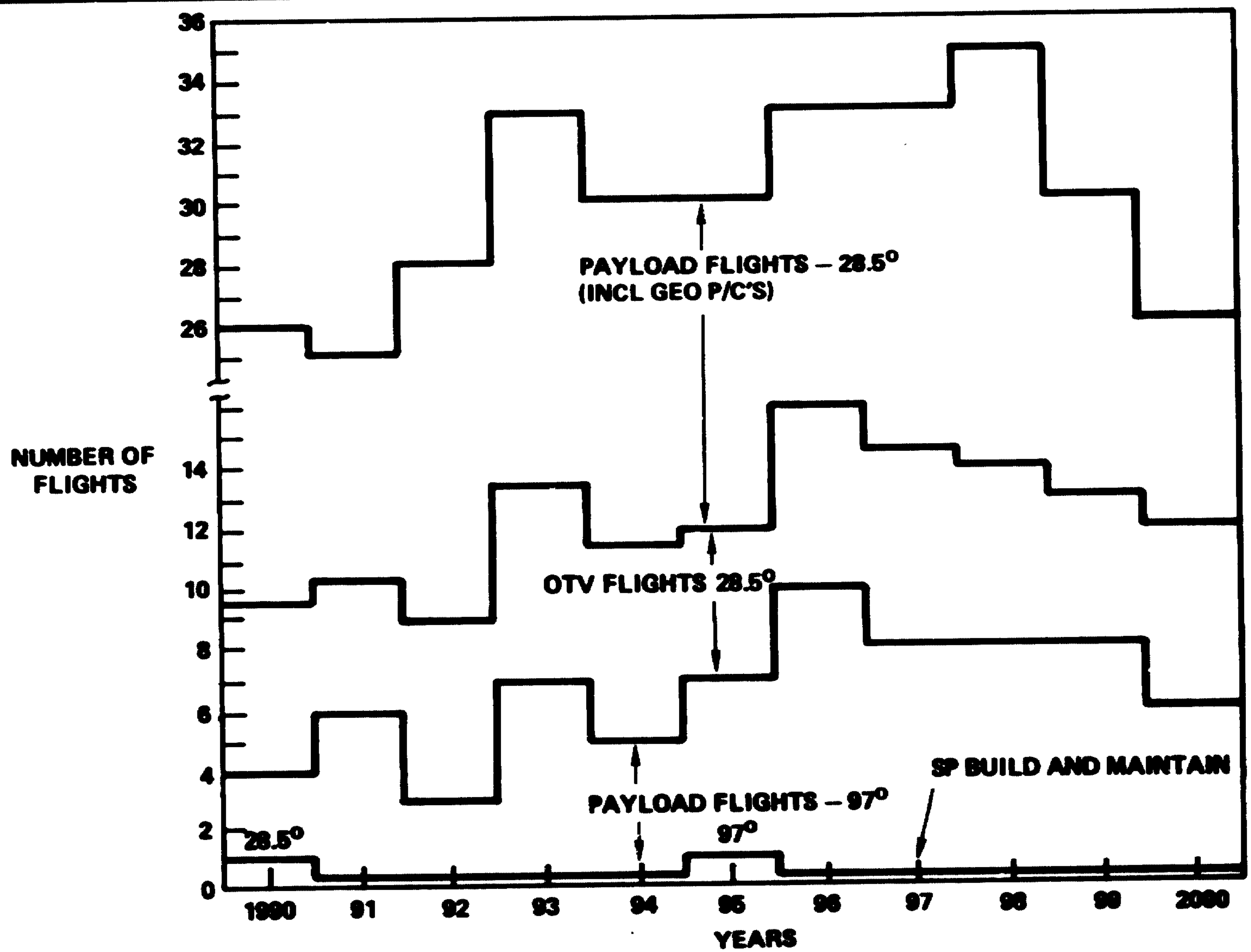
SCENARIO NUMBER 1

28.5° and 97°

Scenario 1 assumed a space platform at 28.5° operational in 1990 and a space platform at 97° operational in 1995. As shown in the figure, each space platform required one Orbiter launch and requires approximately 0.1 Orbiter launches per year to maintain the space platform (primarily for propellant to maintain attitude/altitude).

The figure indicates the cumulative number of Orbiter flights required per year for the 97° and 28.5° orbits in order to launch the specified Mission Model payloads in the required year. Included in the figure is the equivalent number of OTV flights per year to support the Geosynchronous orbit payloads. No space station is required for this scenario.

ORBITER FLIGHTS SCENARIO NUMBER 1



ORBITER FLIGHTS

SCENARIO NUMBER 2

28.5° and 97°

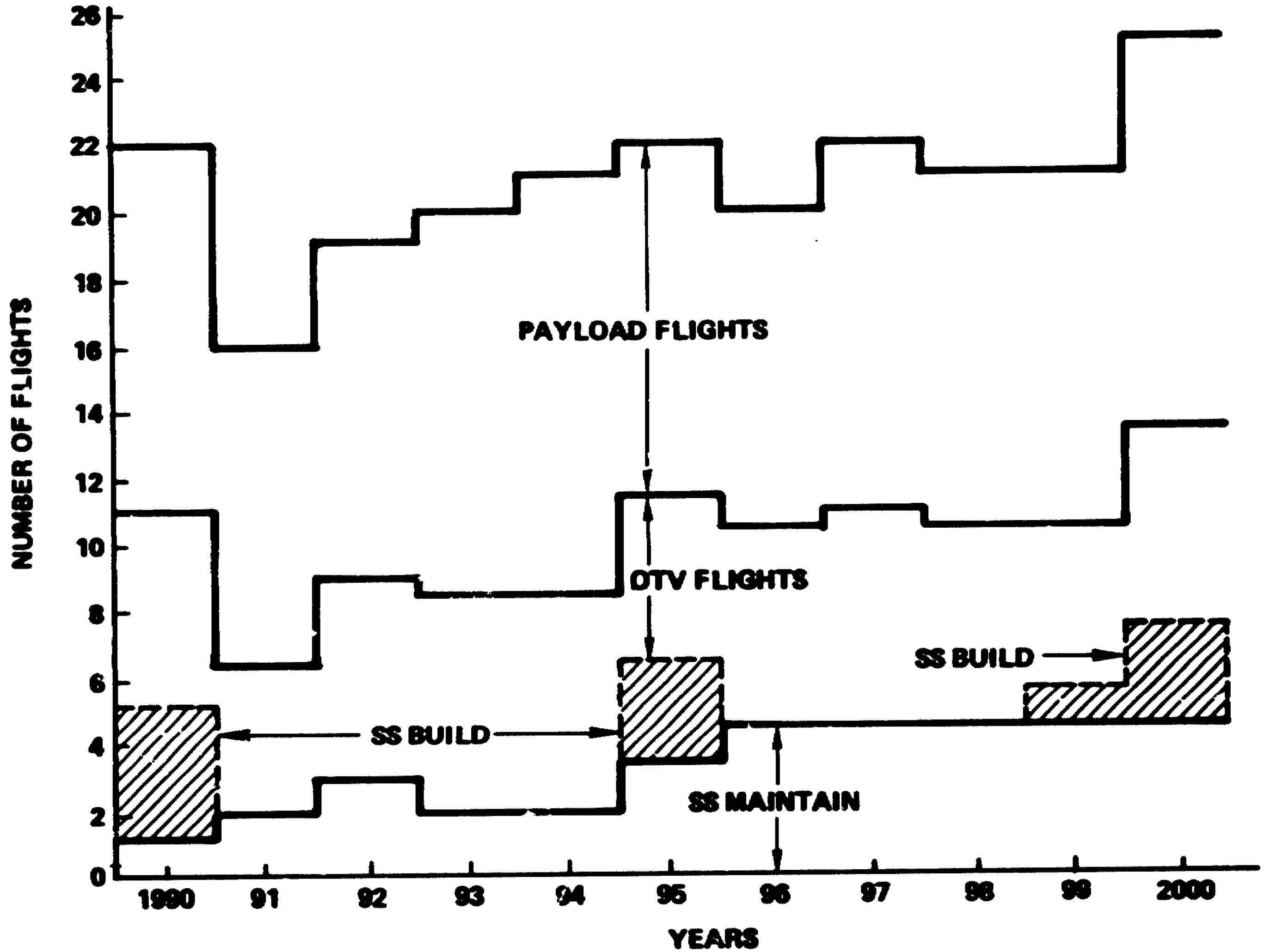
Scenario 2 assumed a space station at 28.5° operational in 1990 with increased operational capabilities added in 1995 and 2000. The total number of flights to build the space station at 28.5° was eleven. To maintain the space station at 28.5° required initially two launches per year for logistics and ultimately 4.5 launches per year from 1996 to 2000.

The initial space station capability for 97° would be operational in 1995. This station required five launches to obtain an initial operational capability with an additional two launches in the 1999 time period for the growth version space station. To maintain this space station required ultimately three launches per year.

The figures indicate the cumulative number of Orbiter flights required per year for the 97° and 28.5° orbits in order to launch the specified Mission Model payloads in the required year. Included in the figures is the equivalent number of OTV flights per year to support the Geo-synchronous orbit payloads.

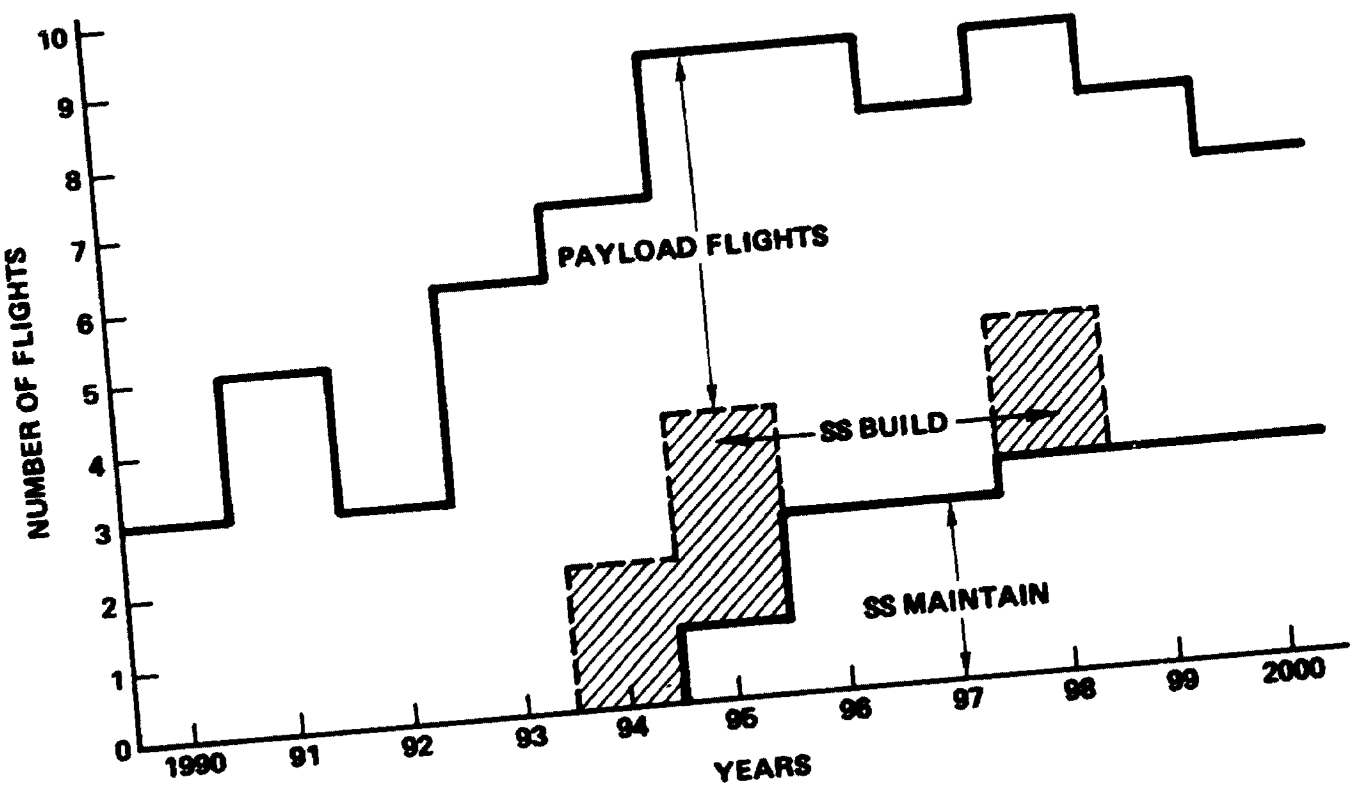
No space platform is required for this scenario.

ORBITER FLIGHTS
SCENARIO NUMBER 2
28.5°



Program Management Division
TRW Space & Technology Group

ORBITER FLIGHTS
SCENARIO NUMBER 2
97°



ORIGINAL PAGE IS OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED

ORBITER FLIGHTS

SCENARIO NUMBER 3

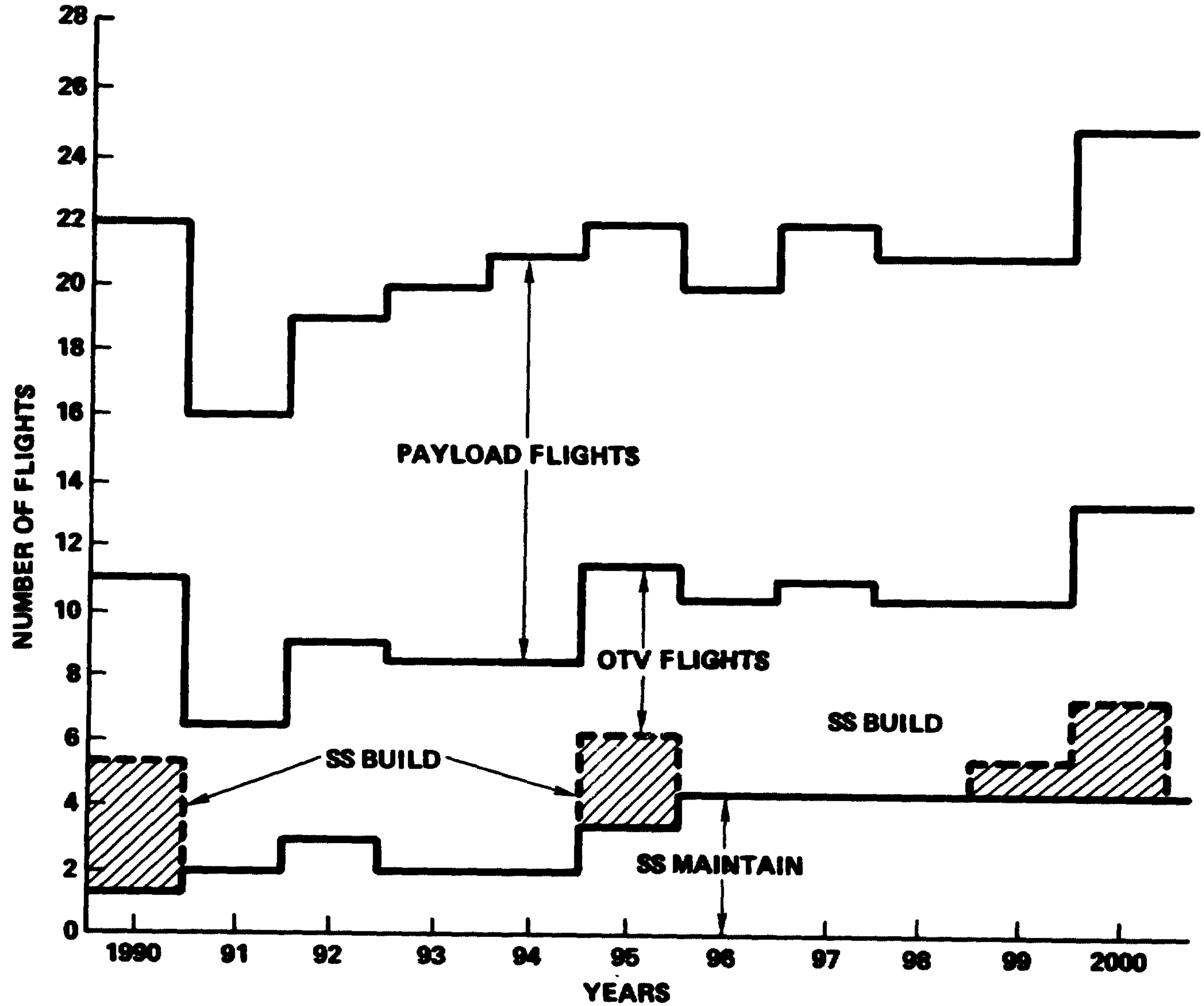
28.5° and 97°

Scenario 3 assumed a space station at 28.5° operational in 1990 with increased capabilities added in 1995 and 2000. The total number of flights to build the space station at 28.5° was eleven. To maintain the space station at 28.5° required initially two launches per year for logistics and ultimately 4.5 launches per year from 1996 to 2000.

For the 97° orbit a large space platform was assumed which required two Orbiter launches. Approximately 0.1 Orbiter launches per year was assumed to maintain the space platform (primarily for propellant to maintain attitude/altitude).

The figures indicate the cumulative number of Orbiter flights required per year for the 97° and 28.5° orbits in order to launch the specified Mission Model payloads in the required year. Included in the figure is the equivalent number of OTV flights per year to support the Geosynchronous orbit payloads.

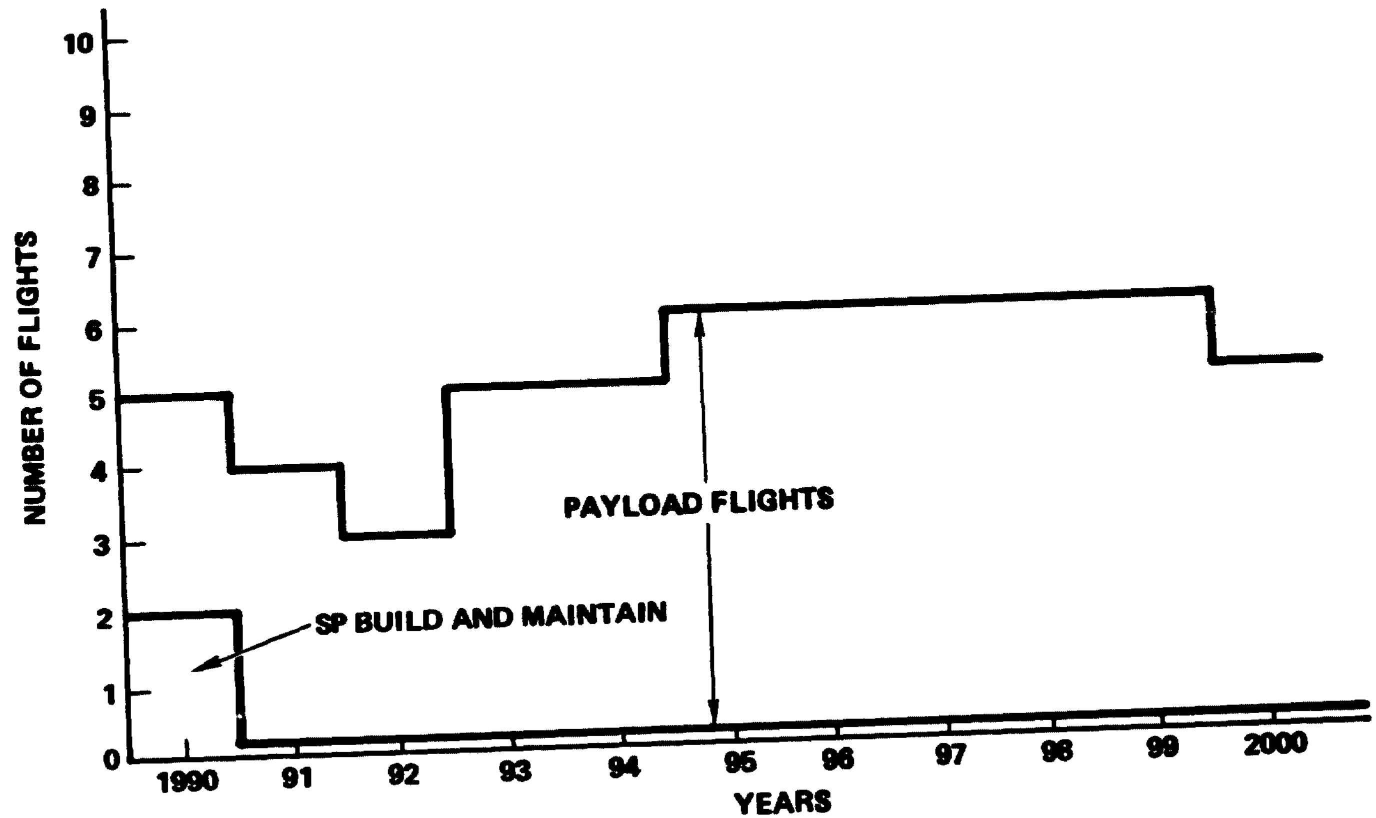
ORBITER FLIGHTS
SCFNARIO NUMBER 3
28.5^{0}



ORIGINAL PAGE IS
OF POOR QUALITY

Program Management Division
TRW Space & Technology Group

ORBITER FLIGHTS SCENARIO NUMBER 3 97°



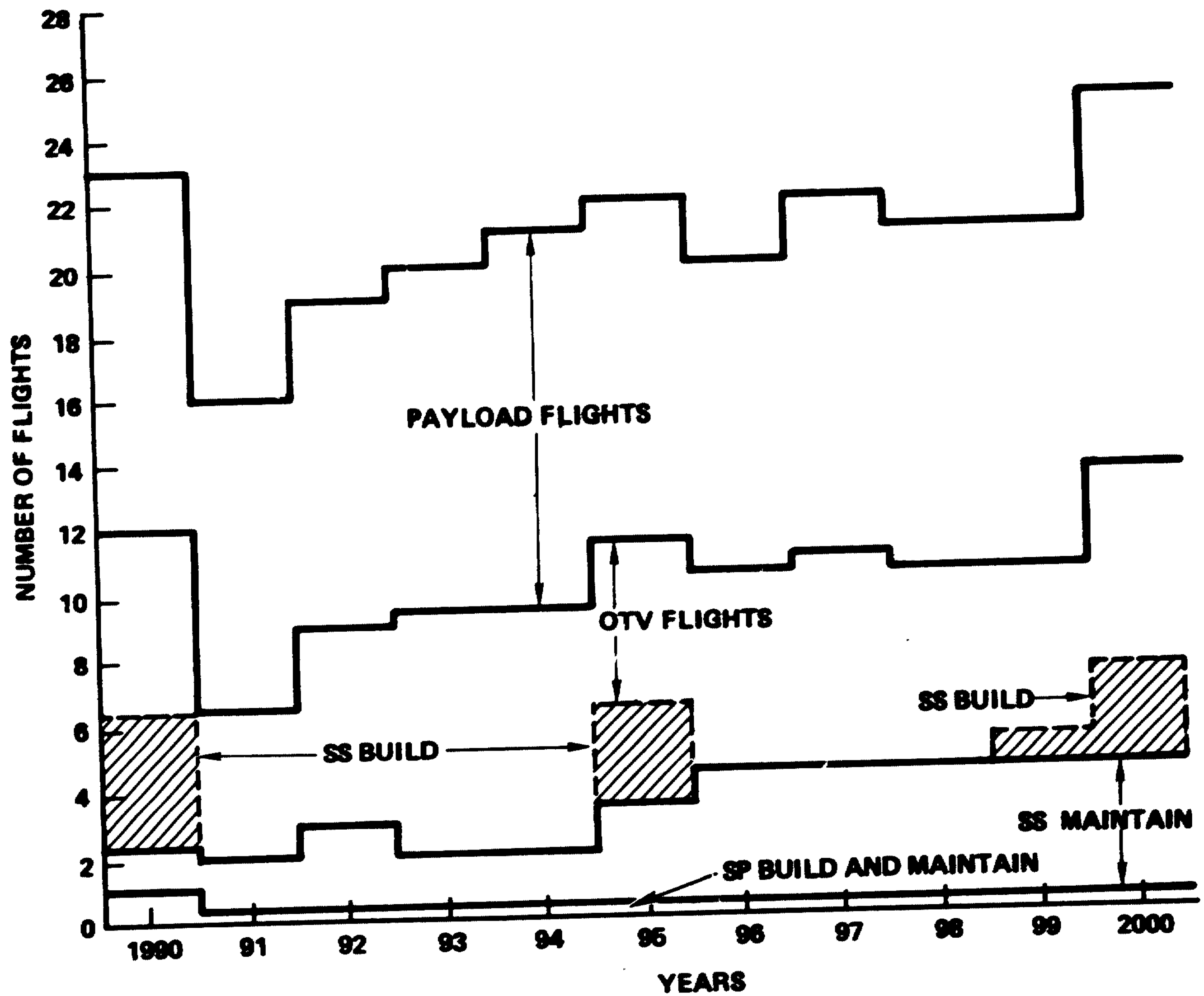
ORBITER FLIGHTS
SCENARIO NUMBERS 4 & 5
28.5°

Scenarios 4 and 5 have identical Orbiter flight requirements for building and maintaining a Space Station and a Space Platform at a 28.5° inclination orbit. In Scenario 4 the modules are launched in the Orbiter with the Orbiter returning after each flight. The Space Station becomes operational at the third flight when the crew is installed.

In Scenario 5 the Orbiter stays in orbit and temporarily forms part of the Space Station which becomes operational at the first flight. The Orbiter which returns to Earth after the third flight, requires modification to enable it to increase its stay-time on orbit.

The chart shows the annual flights for payloads and OTVs needed to support the Mission Model.

ORBITER FLIGHTS
SCENARIO NUMBER 4 & 5
28.5^{0}



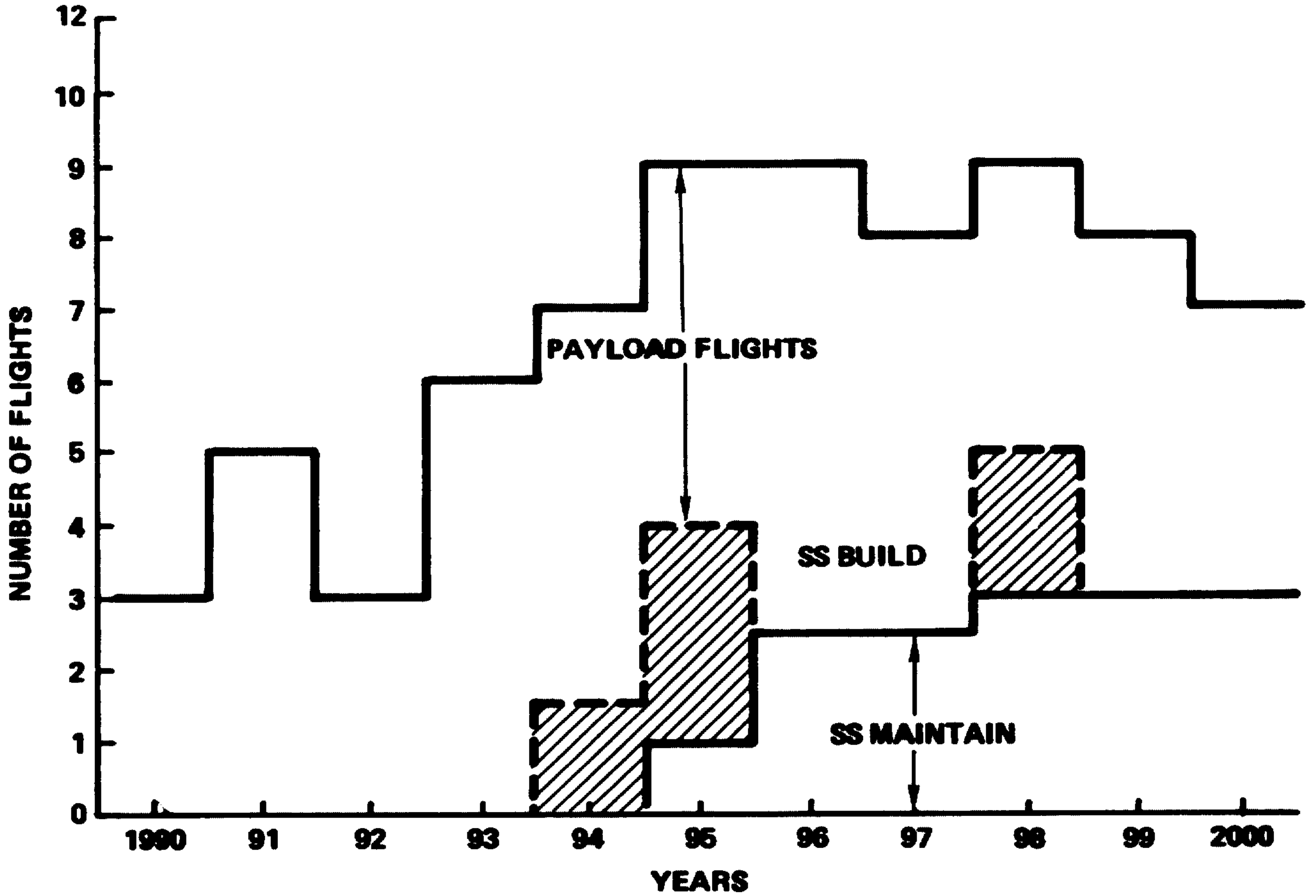
ORBITER FLIGHTS
SCENARIO NUMBERS 4 & 5
97°

Scenarios 4 and 5 have identical Orbiter flight requirements for building and maintaining a Space Station at a 97° inclination orbit. In Scenario 4 the modules are launched in the Orbiter, with the Orbiter returning after each flight. The Space Station becomes operational at the third flight wher the crew is installed.

In Scenario 5 the Orbiter stays in orbit and temporarily forms part of the Space Station which becomes operational at the first flight. The Orbiter which returns to Earth after the third flight requires modification to enable it to increase its stay time on orbit.

The chart shows the annual flights for payloads, and OTVs needed to support the Mission Model.

ORBITER FLIGHTS
SCENARIO NUMBER 4 & 5
97^{0}



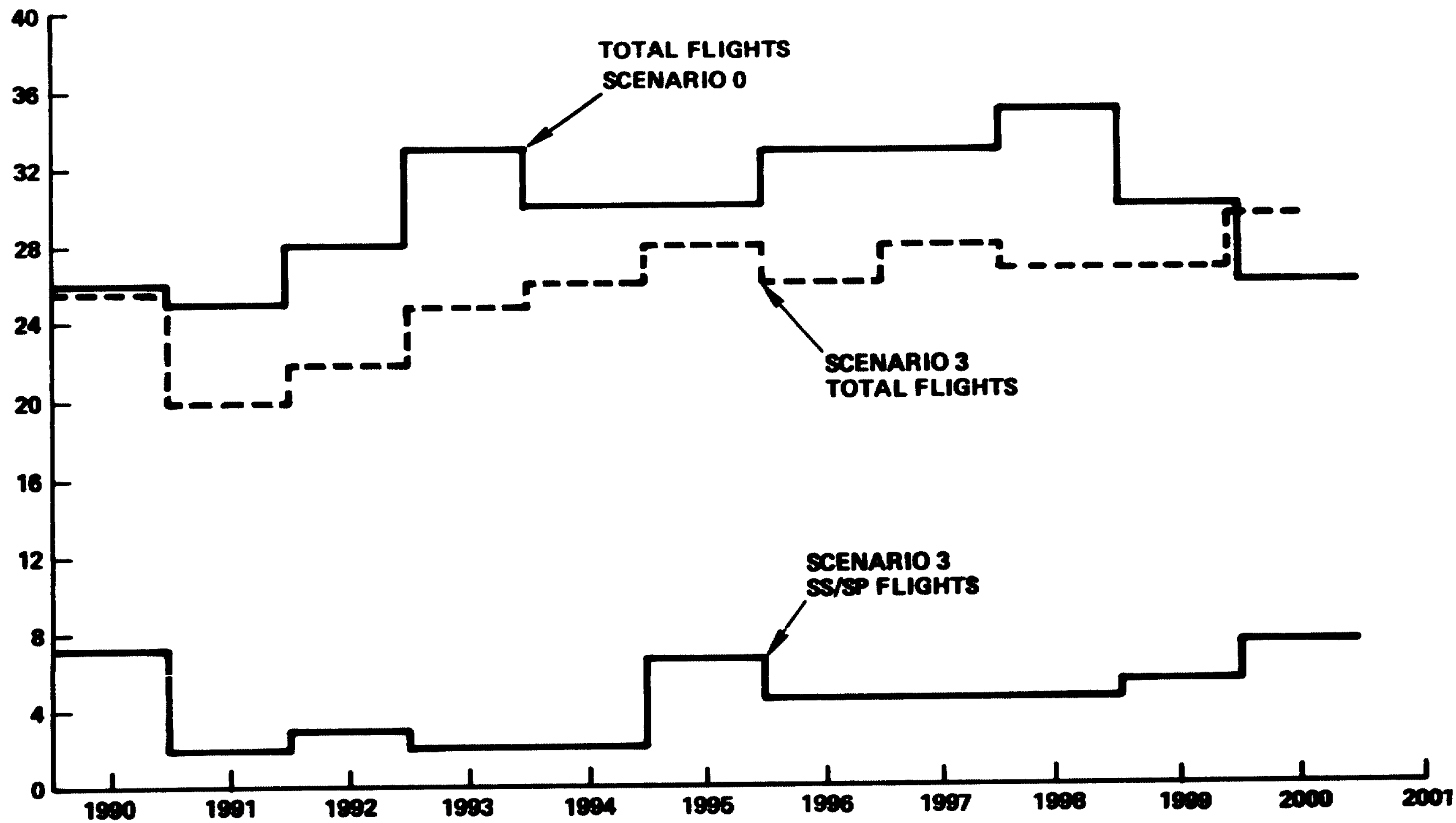
SS INFLUENCE ON ORBITER MANIFESTING

The figure compares the total number of flights for Scenario 0 versus 3. Scenario 0 is Orbiter launches without the assistance of a Space Station, whereas Scenario 3 assumes a Space Station at 28.5° and a large Space Platform at 97°.

This figure is based upon the data developed from manifesting of all payloads and Space Station support flights (build and maintain). The use of a Space Station/Platform allowed for more efficient utilization of the Orbiter even after considering the launches necessary for building and maintaining the Space Station. Over the 10 years period between 1990 and 2000, Scenario 0 requires 329 flights compared to 286 flights for Scenario 3, an excess of 43 flights.

As shown in the figure, for the year 2000, the number of flights for Scenario 3 exceeds Scenario 0. This is caused by the number of flights to build the Space Station (3 in the year 2000) and to maintain the station (4.5). In the year 2001 we would expect the number of flights for Scenario 0 to again exceed Scenario 3.

SS INFLUENCE ON ORBITER MANIFESTING



SPACE STATION SCENARIO COMPARISON

The total number of Orbiter flights for each scenario varies from a minimum of 286 (Scenario 3) to a maximum of 329 (Scenario 0). Despite the fact that Scenario 0 does not include the building and maintaining of a SS, the lower packing of payloads into the Orbiter results in the higher number of flights. The SS presence provides a greater efficiency of Orbiter manifesting.

For all scenarios, by far the greatest percentage of flights are payload flights. Maintaining a SS requires about 3½ times as many flights as does the building of it.

Orbit Transfer Vehicles (OTV's), Apogee Kick Motors (AKM's), and Unmanned Platforms (UP's) are part of the payload flights. These units are lifted by the Orbiter to LEO and put into service at that time.

Space Station Scenario Comparison

CHARACTERISTIC \ SCENARIO NUMBER	0	1	2	3	4/5
TOTAL FLIGHTS	329	329	303	286	304
28.5°	257	257	229	229	230
97°	72	72	74	58	74
PAYLOAD FLIGHTS					
28.5°	257	256	182	182	182
97°	72	70	52	55	52
• BUILD SS	–	–	11/7	11/–	11/7
• MAINTAIN SS	–	–	36.3/15	36.3/–	36.3/15
• BUILD SP	–	1/1	–	–/2	1/–
• MAINTAIN SP	–	0.5/0.7	–	–/1	0.5/–
OTV's	127	127	127	127	127
AKM's	15	15	15	15	15
UNMANNED PLATFORMS	18	6	11	11	6

• X/Y = $28.5^{\circ}/97^{\circ}$

BUILD UP

SS EVOLUTIONARY GROWTH

This chart summarizes the number of Orbiter flights required to build the Space Station and indicates the incremental benefits derived for each evolutionary growth of the station. Also shown is the approximate total weight and size of the Space Station during each time period.

SS EVOLUTIONARY GROWTH

ORBIT	YEAR	ORBITER FLIGHTS	CREW SIZE	NET POWER (kW)	WT. (KLBS)	SIZE-FT (H x L x W)	INCREMENTAL CAPABILITY
28.5°	1990	4	5	30	154	66 x 240 x 120	ATTACHED P/L's, LABORATORY, SATELLITE SERVICING, TMS BASING
	1995	7	8	60	235	72 x 240 x 210	SPACECRAFT ASSEMBLY AND CHECKOUT
	2000	10	10	60	344*	102 x 240 x 210	REFUELING ROTV's
97°	1995	5	3	30	109	66 x 240 x 100	ATTACHED P/L's, SATELLITE SERVICING, TMS BASING
	2000	7	3	30	152	102 x 240 x 132	SPACECRAFT ASSEMBLY AND CHECKOUT

*CRYOGENIC FUEL NOT INCLUDED

ORBITER FLIGHTS TO ESTABLISH LEO/PEO SS

The charts define the number of flights required to establish a Space Station in LEO/PEO.

For the LEO Space Station, the first four flights occurring around 1990, would provide an initial capability including a manned laboratory, a crew of five,electrical power capability of 30 kW after providing power for the Resource Module services. This size Space Station would provide satellite servicing, TMS basing, laboratory experiments and external attach points for payloads mounted to the Space Station.

The interim station (capability in 1995) requires three additional launches, the crew size increases by three and electrical power output increases to 60 kW. This configuration allows for spacecraft assembly and checkout.

The growth version Space Station in the year 2000 supports a crew of 10 people, provides the capability to support larger spacecraft and refuel OTV's.

The PEO Space Station (operational 1990) is smaller in size than the LEO station but requires more flights of the Orbiter to obtain a similar capability. Since the Orbiter payload capability to high inclination orbits is significantly less, to establish the initial Space Station in PEO, requires up to five launches. The initial configuration can accommodate a crew of three with 30 kW of electrical power output after providing power for the Resource Module services. The initial station is configured to provide for satellite servicing, TMS basing and supporting external attached payloads.

The growth version PEO station available in 1998 would provide for spacecraft assembly and checkout and be able to accommodate large payloads.

ORBITER FLIGHTS TO ESTABLISH LEO SS

FLIGHT	YEAR	MODULES ADDED	POWER(KW)	CREW	CONFIGURATION
1	1990	RM, RBM, STM, EA, 3-PAM	30	0	
2	1990	SHM, JM, RMS	30	0	
3	1990	LM, RBM, 2-ALM, AAP, P/L'S	30	4	INITIAL
4	1990	MLM	30	5	
5	1995	2-TM, 2-LBM, BJM, STM, TRACK	30	6	
6	1995	HM, HPA	30	6	
7	1995	RM, CM, MTT, TTT	60	8	INTERIM
8	1999	HM, RMS	60	10	
9	2000	TM, HSM, TRACK	60	10	
10	2000	LM, 2-MCT, ALM	60	10	
11	2000	CTM	60	10	GROWTH

ORBITER FLIGHTS TO ESTABLISH PEO SS

FLIGHT	YEAR	MODULES ADDED	POWER(KW)	CREW	CONFIGURATION
1	1994	RM, RBM	10	0	
2	1994	SHM	30	0	
3	1995	JM, RBM, STM, EA, RMS, 3-PAM	30	0	
4	1995	LM	30	0	
5	1995	AAP, 2-ALM, CM	30	3	INITIAL
6	1998	SHM, HPA	30	3	
7	1998	JM, 2-TM, STM, MTT, TRACK	30	3	GROWTH

SPACE STATION MODULES

This chart is a list of acronyms associated with the Space Station modules.

SPACE STATION MODULES

HABITABLE MODULES

- CM - COMMAND MODULE
- HM - HABITABILITY MODULE
- SHM - SHORT HM
- JM - JUNCTION MODULE
- MLM - MANNED LABORATORY MODULE
- LM - LOGISTICS MODULE
- TM - TUNNEL MODULE
- ALM - AIRLOCK MODULE

SERVICING MODULES

- RMS - REMOTE MANIPULATOR SYSTEM
- HPA - HANDLING AND POSITIONING AID
- MTT - MOBILE TRANSPORT TROLLEY
- TTT - TRANSVERSE TRANSPORT TABLE
- MCT - MOBILE CARRIER TROLLEY
- AAP - ASSEMBLY AREA PLATFORM
- RM - RESOURCE MODULE
- RBM - REBOOST MODULE

CONNECTION MODULES

- PAM - PORT ADAPTER MODULE
- STM - SHORT TUNNEL MODULE
- EA - EXTENSION ARM
- BJM - BOOM JUNCTION MODULE
- LBM - LONG BOOM MODULE
- SBM - SHORT BOOM MODULE

ORBITER MODULES

- OTM - ORBITER TANKER MODULE
- DM - DOCKING MODULE

OPTIONAL MODULES

- HSM - HANGAR SHELTER MODULE
- CTM - CRYOGENIC TANK MODULE
- ERM - EMERGENCY RESCUE MODULE
- SLM - SHORT LOGISTICS MODULE

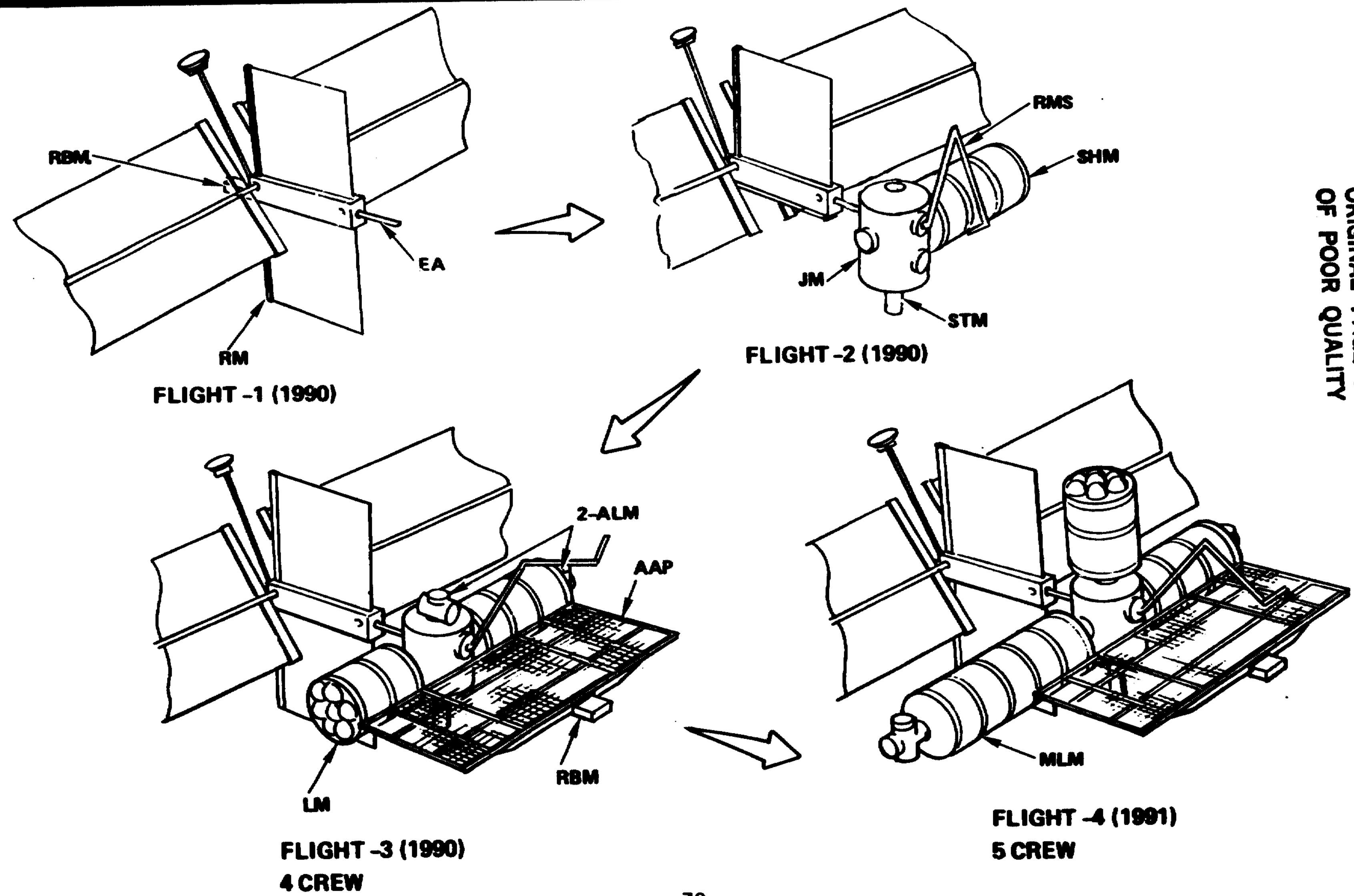
BUILD-UP OF LEO SS (1990-91)

The initial SS shown is assembled in a low altitude, low inclination (28.5°) orbit in the time period 1990-91. It is of a modular construction with all of the modules sized to fit in the Orbiter payload bay and launched in four flights as depicted by the four pictures.

The first flight lifts the RM, RBM and EA followed in the second flight by the JM, SHM, STM and the RMS. The next flight brings up four crew plus two ALM's, AAP, another RBM and a LM to form a small SS which is operational and capable of supporting a range of tasks.

The fourth and last flight for the initial SS carries the MLM and another member of the crew. Notice the rearrangement of some of the modules; one of the ALM's is moved from the JM to the far end of the MLM and the LM berths to the vacated place on the JM.

BUILD-UP OF LEO SS (1990-91)



ORIGINAL PAGE IS
OF POOR QUALITY

BUILD-UP OF LEO SS (1992-95)

The LEO SS advances in four stages (flights 5 through 8) from the initial to the interim size SS.

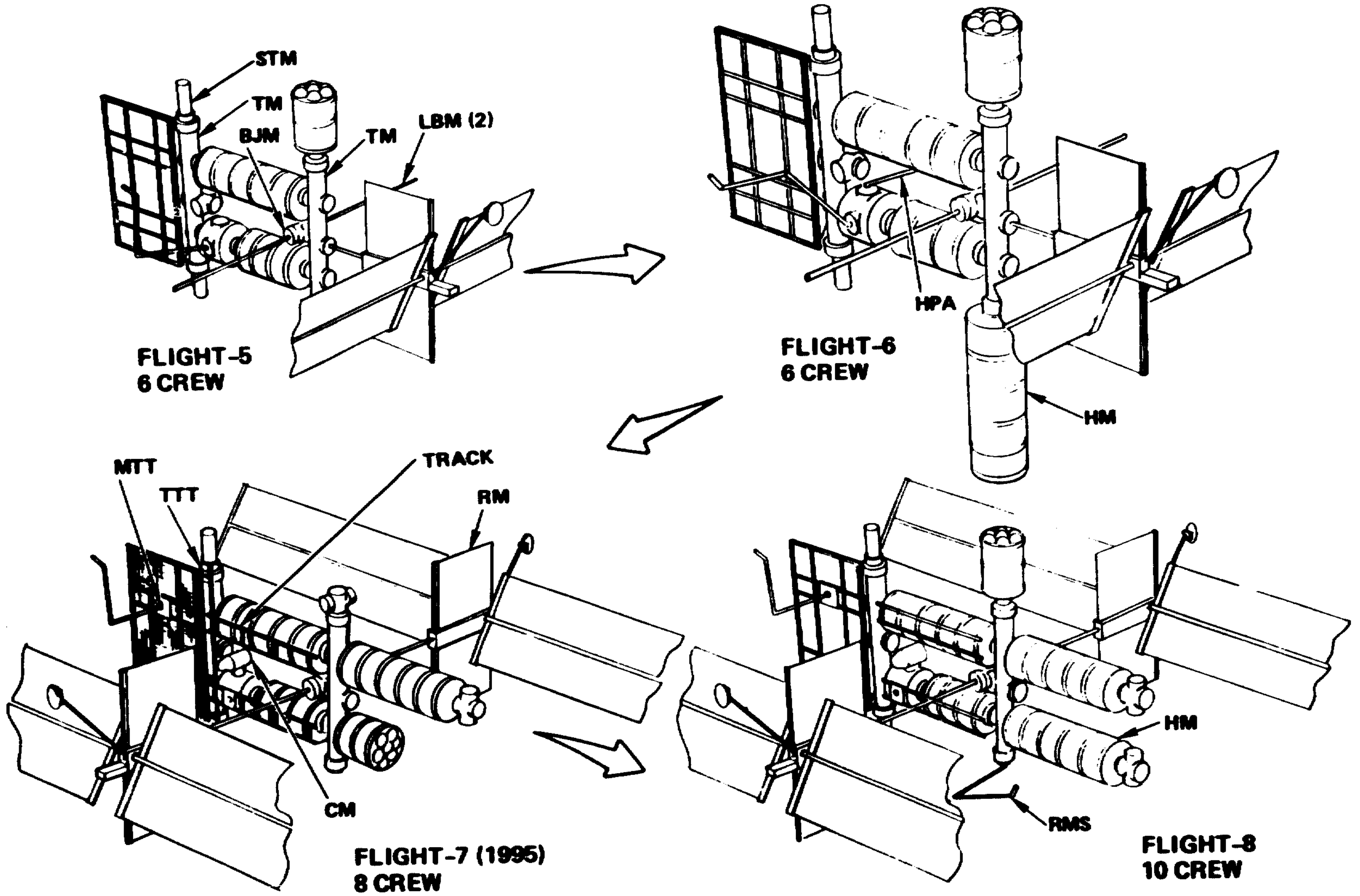
Flight 5 adds two TM's, another STM, the BJM, 2 LBM's and a sixth crew member. The configuration of the station is rearranged to bring the major modules parallel to each other and interconnected by the two TM's. The RMS now has a number of ports to which it can be berthed.

Flight 6 lifts a long HM and a HPA.

The 7th flight contributes two crew members, the second RM, some components of the track/trolley system and the CM. The first RM is relocated, and the axis of the solar arrays undergoes a 90° change.

The 8th and last flight of this group adds two crew members, the last HM and a second RMS.

BUILD-UP OF LEO SS (1992-95)



ORIGINAL PAGE IS
OF POOR QUALITY

BUILD-UP OF LEO SS (1996-2000)

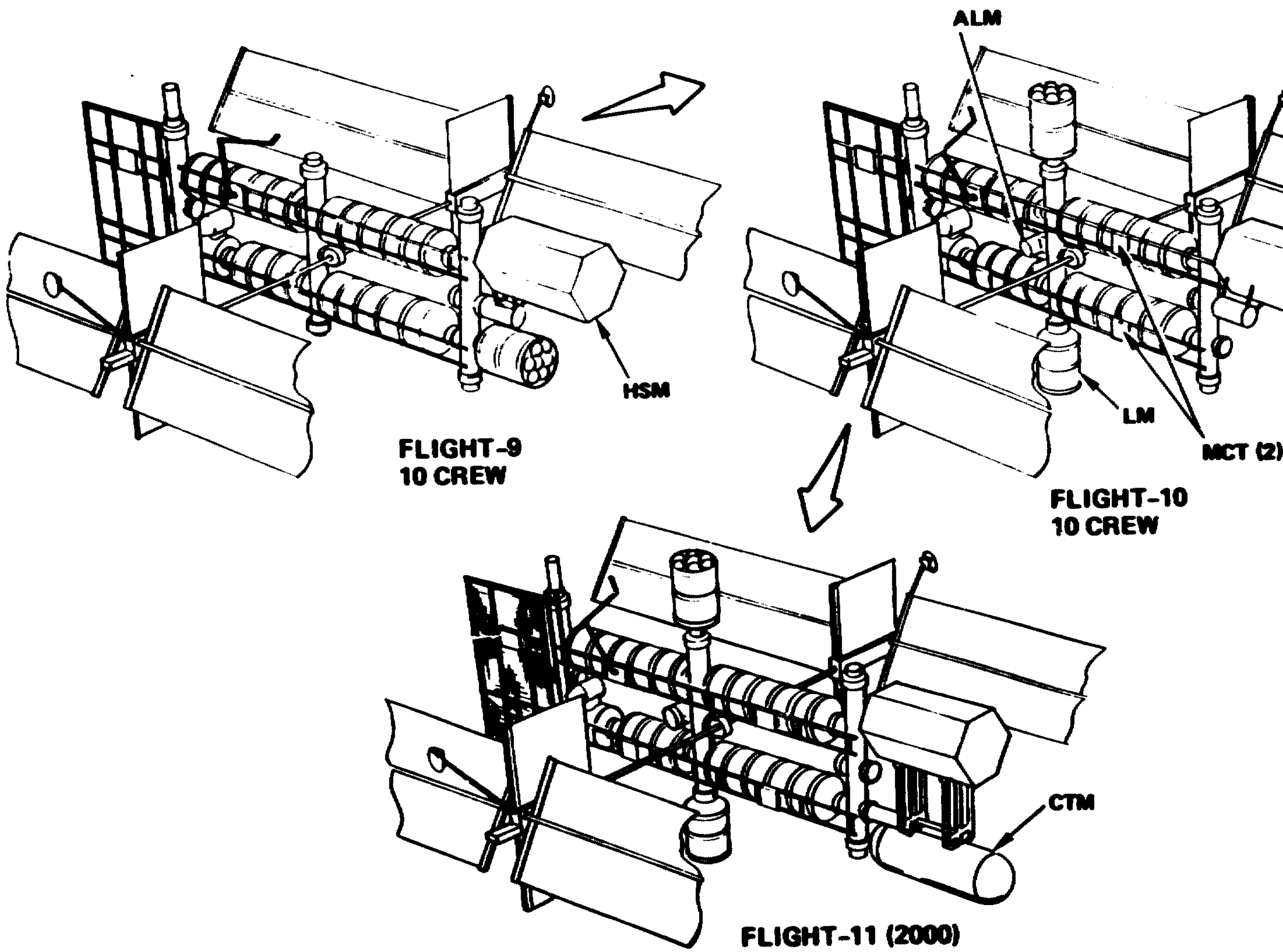
Three flights are required to change the station from the interim to the fully developed growth version.

Flight 9 is used for the HSM, an optional module whose usefulness is undecided.

The 10th flight lifts a second LM and the final components of the track/trolley system.

The final flight to establish the completed SS adds the CTM for refueling ROTV's.

BUILD-UP OF LEO SS (1996-2000)



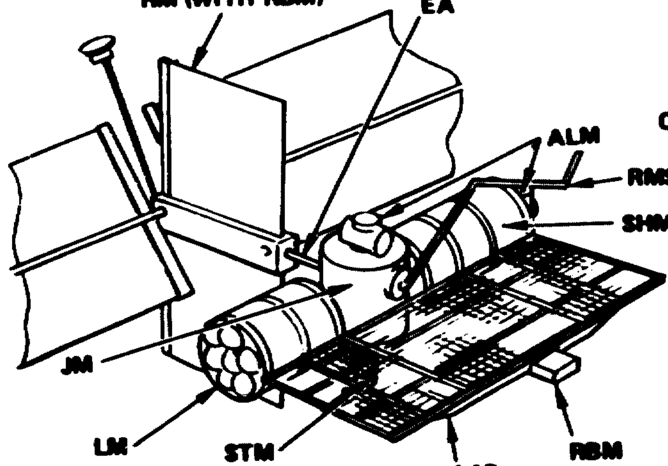
PEO OR GEO SS CONFIGURATION

This smaller PEO station is designed for the reduced lift capabilit. of the Orbiter at high inclination orbits, consequently the heavy modules such as the MLM and the long HM are absent. Six and one-half Orbiter launches are required for the PEO SS and its crew, the half launch is an Orbiter shared with a payload.

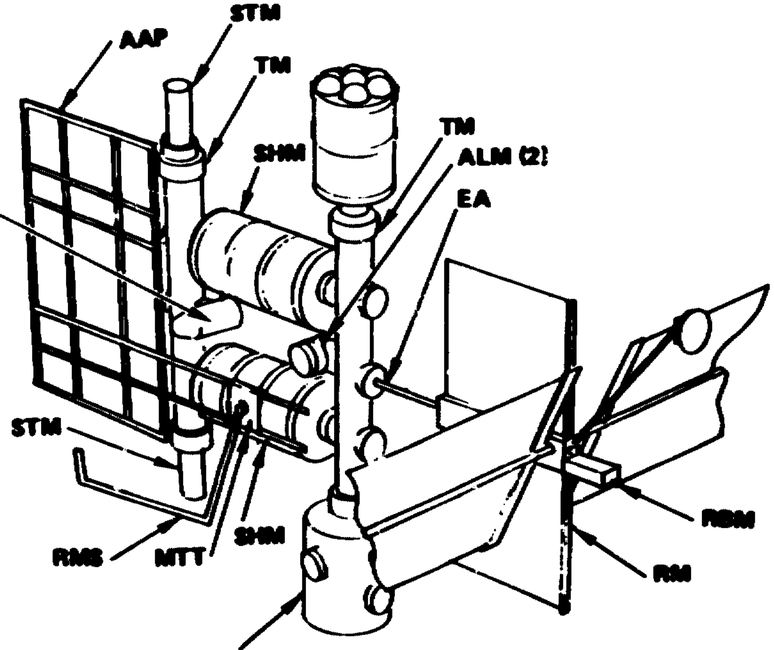
It is planned to assemble the GEO SS in LEO at 28.5° check it out, and then boost it to GEO using an ROTV with added fuel tanks.

The lower picture shows an alternative version of the growth SS with a nuclear power module replacing the large RM.

PEO OR GEO SS CONFIGURATION

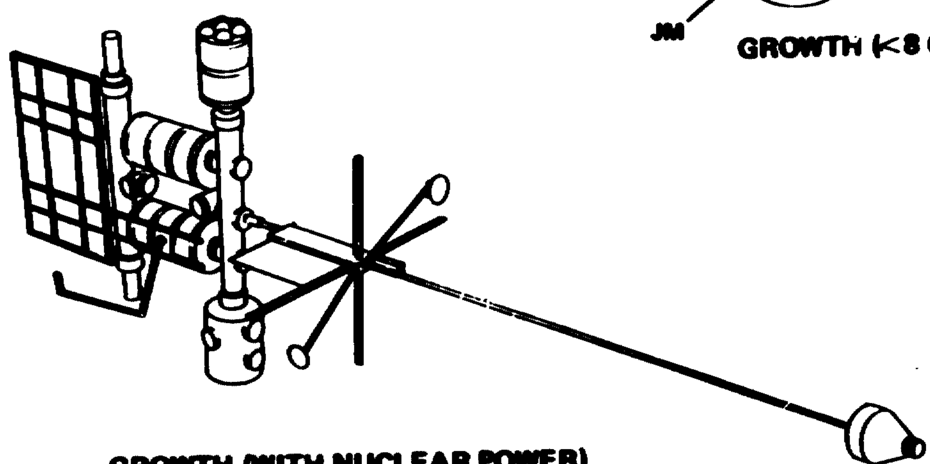


INITIAL (3 CREW)



GROWTH (<8 CREW)

ORIGINAL PAGE IS
OF POOR QUALITY



GROWTH (WITH NUCLEAR POWER)

PRECEDING PAGE BLANK NOT FILMED

CHARACTERISTICS

SS MAJOR MODULE SIZES

This table provides the weight and overall length of the major modules that comprise the Space Station. For those modules that normally would contain fluids, such as water or propellant, the weights shown are for a fully loaded module except where noted (i.e., the cryogenic tank).

SS MAJOR MODULE SIZES

MODULE	LENGTH (FT)	WEIGHT (KLBS)
RESOURCE	33	26.7
HABITABILITY	52	38.5
SHORT HABITABILITY	35	29.9
MANNED LABORATORY	52	30.1
JUNCTION	17	9.0
LOGISTICS	26	41.6
TUNNEL	52+	5.4
AIRLOCK	6+	0.7
COMMAND	10+	0.8
ASSEMBLY AREA PLATFORM	52+	1.0
HANGAR SHELTER #	52+	5.0
CRYOGENIC TANK #	52	15.0*
EMERGENCY RESCUE #	10+	4.0

+ EQUIVALENT LENGTH (< 15 FT. DIA.)
# OPTIONAL
* WEIGHT EMPTY

RESOURCE MODULE (RM) DESIGN

As its name implies, the RM is a unit which supplies many of the basic utility requirements for a space vehicle. The modular RM can be used in whole or in part as part of an SP, an UP or the SS. Because of its design, it is well suited to fit into the evolutionary buildup shown in this briefing. A single RM is sufficient to support the initial SS, while two RM's are required for the larger SS. Additional RM's can be attached if this ever becomes necessary.

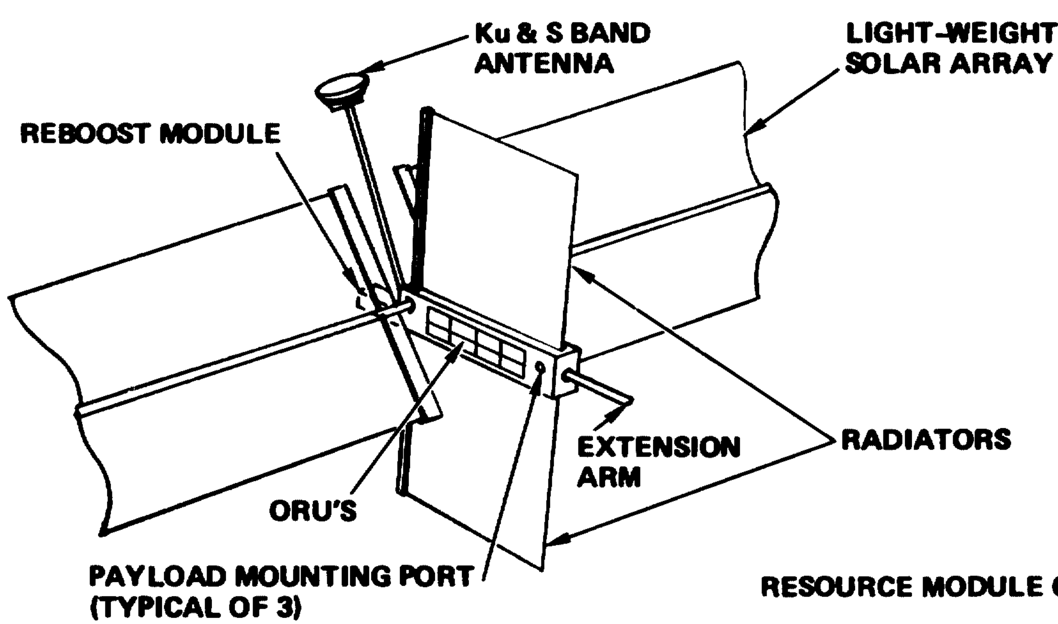
The RM supplies 30 kw net of electrical power generated by light-weight silicon cell solar arrays, with NiCd batteries for energy storage, and extendable radiators capable of dissipating all of the RM and attached payload excess heat. Avionics include attitude and momentum control, plus communications and deployable antennas. A hydrazine propulsion system for orbit altitude maintenance, altitude control and momentum unloading is one of the features provided by the RM.

A feature of the RM is its modular design which renders it particularly suitable for in-space servicing and replacement/repair operations. Major functions including a reboost module (RBM) are the plug-in type and are expected to be replaced on a routine basis. All subsystems are on ORU's.

The RM is equipped with 3 berthing ports which are intended for payload mounting.

RESOURCE MODULE DESIGN

- RESOURCE MODULE DESIGN SHALL PROVIDE AS A MINIMUM:
  - REGULATED ELECTRICAL POWER GENERATION (30 KW, NET PER RM)
  - ENERGY STORAGE TO HANDLE PEAK LOADS AND ECLIPSES
  - ATTITUDE AND MOMENTUM CONTROL
  - COMMUNICATION EQUIPMENT AND ANTENNAS
  - SELF COOLING
  - PROPULSION FOR ALTITUDE MAINTAINENCE AND MOMENTUM UNLOADING
  - THREE PAYLOAD BERTHING PORTS
- RM HAS COMMON DESIGN MODULARITY WITH SPACE PLATFORM
- USES ORBITAL REPLACEMENT MODULES (ORU'S) FOR ALL SUBSYSTEMS



RESOURCE MODULE CONFIGURATION

HABITABILITY/LABORATORY MODULES

Long HM

The long HM is the major living space for large SS's and is intended to house a crew of four in relatively comfortable surroundings for an indefinite period. It provides for sleeping, eating, cooking, hygiene and recreation as well as serving as a control center for the SS. By reducing the space allocated for crew comfort/convenience, substantial weight and volume may be diverted to payload accommodation.

Use of multiple self-contained HM's provides the redundancy required for crew safety in the event of the loss of pressure in one module.

Short Habitability Module and Junction Module

The SHM is a short version of the long HM designed for launch with the JM. The SHM and JM together are the same length as one long HM, and make one Orbiter launch. They are used together to form the basis of the initial SS and provide for a crew of four but with less comfort than the long HM.

Manned Laboratory Module

The MLM is similar in appearance and size to the long HM but its function is to provide more space for payloads. It has life support equipment necessary for "working in" but not "living in" the module.

HABITABILITY/LABORATORY MODULES

Long Habitability Module

- Five Spacelab sections, or equivalent
- Life support provisions for a crew of 8 for 21 days
- Independent/redundant ECLSS and thermal control
- Provides volume and utilities for internal payloads/experiments
- Windows/viewing ports as required
- Outer shell provides radiator and meteoroid/debris/radiation protection

Short Habitability Module

- Same as long habitability module except three Spacelab sections long
- Less spare volume and may have less crew comforts

Manned Laboratory Module

- Same as long habitability module but contains biological experiments/payloads
- No living provisions but provides ECLSS for crew of four

Junction Module

- 2 Spacelab segments in length
- Connects short habitability module in interim and growth configurations
- Emergency living provisions for a crew of four

HABITABILITY MODULE MASS (LBS)

This chart summarizes the weight estimates made for the habitable modules. Each habitable module (except the MLM) has 21-day emergency supplies. The possible internal payload accommodation of weight and volume are also shown. The MLM may require a large hatch to allow easy change-out of large internal payloads. The MLM is not configured for continuous living (i.e., sleeping, eating, etc.), so that a simpler ECLSS will suffice.

These mass statements are based on the following assumptions:

- The Orbiter will lift the SHM and the JM in one launch.
- The structures are approximately 0.40" thick aluminum for micro-meteoroid protection.
- The thermal control system is a radiator covering the exterior of the SHM. It also serves as a micro-meteoroid shield.
- The ECLSS is a partially-closed loop system.
- Supplies/comsumables for 90 days are stored in the logistics module and not in the HMs.
- The JM has provisions for 21-days to provide against the loss of the SHM. The JM will also have access to the LM.

HABITABILITY MODULE MASS (LBS)

FUNCTION/SUBSYSTEM	LHM	SHM	JM	MLM
STRUCTURES AND MECHANISMS	19,400	15,000	6,800	19,400
THERMAL	7,500	4,500		7,500
AVIONICS	1,000	1,000		
ELECTRICAL POWER	1,450	1,450		1,450
DATA MANAGEMENT	1,300	1,300		
ECLSS AND CREW ACCOMMODATION	4,400	3,100		1,800
MISSION EQUIPMENT	2,200	2,200		
	37,250	28,550	6,800	30,150
21 DAYS EMERGENCY SUPPLIES	1,250	1,250	1,000	
	38,500	29,800	7,800	30,150
PAYLOAD ACCOMMODATION	21,000	21,900		29,350
TOTAL	59,500	51,700	7,800	59,500
PER-LAUNCH	59,500	59,500		59,500

AVAILABLE VOLUME FOR PAYLOADS (FT^3):

LHM	2,200
SHM	540
JM	0
MLM	2,500

ECLSS RESUPPLY REQUIREMENTS (LB M)

This chart lists the weight in lbs of the resupply requirements of a crew of 8 for 90 days, distinguishing between the three phases of development of the ECLSS.

ECLSS RESUPPLY REQUIREMENTS (LBM)

ITEM	PHASE 1	PHASE 2	PHASE 3
STORAGE & TRANSFER	5,056	4,114	3,366
SUPPLIES	6,728	6,200	6,200
CONSUMABLES	23,082	17,406	14,484
TOTAL	34,866	27,720	24,050

- BASED ON 8 CREW FOR 90 DAYS

LOGISTICS MODULE

The LM is a pressure-tight vehicle which berths to the SS and is used as a pantry and supply room until replaced by a fresh LM. The interior volume is 2000 ft^3 of which half is taken by supply lockers and a freezer compartment. The LM carries supplies for eight people for 90 days.

One interesting variant of the standard LM is its adaptation as a Personnel Transfer Module. There is ample room inside the LM for four people, four space suits and the necessary life support systems for durations of up to two days. This is suitable for transferring crew from a low orbit Orbiter to a higher orbit SS using the TMS, or for supplying a GEO SS by OTV.

LOGISTICS MODULE

- PROVIDES RESUPPLY FOR SS CONSUMABLES
- CHANGEOUT OF LM IS ACCOMPLISHED ON SCHEDULED BASIS
- ONE INTERNAL PORT FOR CREW ACCESS TO FOOD, SUPPLIES, REPAIR MATERIALS, ETC.
- EXTERNAL SUPPLIES PROVIDE WATER, OXYGEN, PROPELLANTS, ETC., FOR PUMPING TO SPACE STATION
- RETURNING LM CONTAINS WASTE AND TRASH
- APPROXIMATELY TWO SPACELAB SEGMENTS LONG

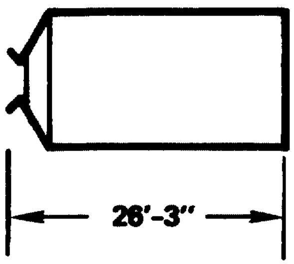
LOGISTICS MODULE (LM)

The Logistics Module is sized to supply 8-men for 90-days. It has a weight of 13,865 lbs. for structure and systems excluding "mission equipment" (see "Resupply Requirements" chart). The weight of supplies listed in the table is the minimum required based on the type (i.e., Phase) of the ECLSS considered. The LM has a standard docking interface at one end for mating to the Space Station and a hatch for closeout. The interior is airtight and is designed as a "walk in pantry" or storeroom. It contains lockers and a refrigerated section for frozen foods. On the exterior of the LM are tanks and plumbing for water and other liquids, gases or fuels as required. There are hose connections located around the docking interface for transfer of liquids and gases. Waste water, trash, etc., are carried back to earth on the return journey. Some thought was given to using the LM as a crew transfer module moved by the TMS. This can be done with the addition of about 2,000 lbs. including 4 EVA suits. The LM would also have internal and external provision for Orbital Replacement Unit (ORU) transportation.

The SLM is similar to the LM except that it is smaller and lighter to comply with the reduced lift capability of the Orbiter in polar orbits.

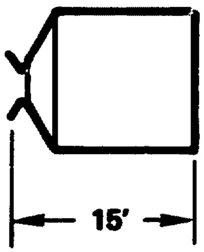
LOGISTICS MODULE (LM)

- **TWO SIZES**



- **LOGISTICS MODULE**
  - **SUPPLIES 8 MEN FOR 90 DAYS, 28.5° ORBIT**

SS ECLSS	LM STRUCTURE, LBS.	SUPPLIES, LBS.	TOTAL LBS.
PHASE 1	13,865	32,066	45,931
PHASE 2	13,865	27,720	41,585
PHASE 3	13,865	24,050	37,915



- **SHORT LOGISTICS MODULE, POLAR ORBIT**

SS ECLSS	SLM STRUCTURE	SUPPLIES	TOTAL	MAN DAYS
PHASE 1	8,000	10,500	18,500	3 x 90 = 270
PHASE 2	8,000	21,000	27,000	3 x 180 = 540

- **THE ORBITER (28.5°) CAN LAUNCH**
  - **LM + SLM + DM + 38,000 LBS. SUPPLIES**

OTHER SS MODULES

This chart covers some of the small SS modules. Each module is equipped with a berthing interface(s) for easy assembly with other SS modules.

OTHER SS MODULES

AIRLOCK MODULE

- SAME AS STS AIRLOCK WITH ADDITION OF BERTHING MECHANISM
- AT LEAST TWO AIRLOCKS PER SS
- CONTAINS TWO SPACE SUITS

PORT ADAPTER MODULE

- ADAPTS LARGE SS BERTHING PORT TO SMALLER SP-TYPE BERTHING PORT
- MOUNTS RBM'S, RMS, HPA, EXTERNAL PAYLOADS, ETC. TO SS PORTS

SHORT TUNNEL MODULE

- PROVIDES INCREASED DISTANCE BETWEEN SS AND ORBITER FOR BERTHING

EXTENSION ARM MODULE

- PROVIDES CLEARANCE DISTANCE FOR SMALL SS FROM SINGLE RM

REMOTE MANIPULATOR

- SIMILAR TO STS RMS WITH INCREASED ANGULAR TRAVEL OF LOWER THREE AXES
- CARRIED UP TO SS AT STARBOARD LOCATION OF STS

Long Boom Module, Boom Junction Module

These two units are used in conjunction with each other for mounting two RM's to the interim or growth SS's.

Mobile Transport Trolley, Transverse Transport Table, Mobile Carrier Trolley

These mobile units use the rail system attached to the outsides of the SS modules to move the RMS, the HPA, satellites, OTVs etc. about the SS as required.

Assembly Area Platform

This is a lightweight rigid structure which folds into a compact unit for transportation. It is equipped with a rail spur for use of the MTT and MCT. The AAP is intended for storage of large items and for repair or servicing of satellites and OTVs. It has rails and multiple attach points and attach devices for securing the vehicles being worked on.

Hangar Shelter Module

If a HSM is used its most probable form will be a lightweight foldable structure which affords protection from the sunlight, provides footholds, work platforms, lights and power outlets and possibly some micrometeoroid protection.

OTHER SS MODULES
(CONT'D)

LONG BOOM MODULE

- JOINS RM'S TO LARGER SS VERSIONS

BOOM JUNCTION MODULE

- CONNECTS TO TM AND INTERFACES TO TWO LMB'S

MOBILE TRANSPORT TROLLEY

- RUNS ON RAILS ATTACHED TO SS MODULES TO PROVIDE MOBILITY FOR RMS/HPA
- PROVIDES LONGITUDINAL (X-AXIS) MOVEMENT

TRANSVERSE TRANSPORT TABLE

- RUNS ON RAILS ATTACHED TO TM
- PROVIDES TRANSVERSE (Y-AXIS) MOVEMENT FOR MTT

MOBILE CARRIER TROLLEY

- SIMILAR TO MTT BUT ACCOMMODATES OTV'S OR OTHER LARGE BODIES

ASSEMBLY AREA PLATFORM

- PROVIDES A WORK AND ASSEMBLY AREA FOR SS
- LONGITUDINAL RAILS ON ONE SIDE, STORAGE AREA WITHIN AND ON OPPOSITE SIDE

HANGAR SHELTER MODULE

- PROVIDES SERVICE/REPAIR AREA FOR LARGE SPACECRAFTS/OTV'S
- HANGER ROTATABLE IN ORDER TO REDUCE AERODYNAMIC TORQUES

OTHER SS MODULES (Continued)

This chart covers the remaining small SS modules. Each module is equipped with a berthing interface(s) for easy assembly with other SS modules.

OTHER SS MODULES (CONT'D)

HANDLING AND POSITIONING AID

- SIMILAR TO RMS WITHOUT LOWER ARM AND WITH FOUR DEGREES OF FREEDOM
- CARRIED UP TO SS AT STARBOARD LOCATION OF STS

TUNNEL MODULE

- JOINS OTHER SS MODULES TOGETHER TO PROVIDE INGRESS/EGRESS WITH EIGHT PORTS
- MINIMUM ATMOSPHERE AND THERMAL CONTROL

COMMAND MODULE

- VIEWING PLATFORM FOR ALL SS EXTERNAL ACTIVITIES
- PROVIDES CONTROLS FOR RMS AND OTHER MOVABLE DEVICES

OPTIONAL SS MODULES

Cryogen Tank Module

A CTM for 150,000 lbs of fuel is 14' diameter x 52' long, the maximum size for the Orbiter. It is refilled from the Orbiter Tank Modules which are used to bring up cryogenic propellant.

Emergency Rescue Vehicle

This small (Gemini-sized) module is used as an ambulance to return to Earth an injured or sick person who cannot await the Orbiter. It is a relatively simple vehicle with the minimum of life support and avionics on board. It would contain a heat shield, descent parachute and flotation gear.

Nuclear Power Module, Nuclear Boom Module, Small Resource Module

These modules are used in conjunction with each other for conversion from solar power to nuclear power. The small resource module supplies those resources supplied by the conventional resource module for the non-nuclear SS.

OPTIONAL SS MODULES

CRYOGEN TANK MODULE

- REQUIRED TO STORE FUEL FOR ROTV'S
- INCLUDES NECESSARY THERMAL CONTROL, RELIQUIFACTION, PUMPS, ETC.
- CAN ACCOMMODATE UP TO 125,000 LBS. OF LO_2 AND 25,000 LBS. OF LH_2

EMERGENCY RESCUE MODULE

- PROVIDES RESCUE CAPABILITY FOR MEDICAL EMERGENCIES
- CAN PROVIDE LIFE SUPPORT FOR TWO PEOPLE FOR TWO DAYS
- SIZED AND CONFIGURED SIMILAR TO GEMINI CAPSULE

NUCLEAR POWER MODULE

- USED FOR NUCLEAR POWERED SS (NO SOLAR/BATTERY POWER REQUIRED)
- PROVIDES A MINIMUM OF 25 kW OF POWER UNDER ALL TWO-FAILURE CONDITIONS

NUCLEAR BOOM MODULE

- CONNECTS SMALL RESOURCE MODULE TO NUCLEAR POWER MODULE
- PROVIDES ADEQUATE DISTANCE ($>$150 FT.) FROM MANNED MODULES TO ASSURE SAFE LEVEL OF RADIATION

SMALL RESOURCE MODULE

- USED IN CONJUNCTION WITH THE NUCLEAR POWER MODULE
- PROVIDES SAME SERVICES AS BASELINED RESOURCE MODULE

ORBITER TANK MODULE (OTM)

An Orbiter Tank Module (OTM) sized for 50,000 lbs. of cryogen is sized as shown. This is the normal maximum load that the Orbiter can lift to 150 nmi allowing 10,000 lbs. for Airborne Support Equipment (ASE).

The OTM is a removable module, located in the Orbiter cargo bay. It is used to "ballast up" the Orbiter to its full lift-off mass capability whenever other payloads are lighter than the full capability and when those payloads are short enough so that space is available. This "ballast" is usable cryogenic fuel. The OTM also aids in Orbiter cargo c.g. location control, being at the aft end of the bay.

The OTM also provides a place into which any available ET residual fuel can be pumped.

If no other payload mass is present, the OTM is full at lift-off and 50,000 lbs. of cryogen is carried to the SS. As the other payload mass increases, the OTM fuel at lift-off decreases but volume is made available for subsequently transferred ET fuel.

ORBITER TANK MODULE

- ORBITER TANK MODULE (OTM)
  - FITS INTO THE CARGO BAY OF THE ORBITER
  - EASILY REMOVABLE FOR CHANGEOUT
  - 14.5' DIAMETER X 24' LONG
  - WEIGHT TO ORBIT:

50,000 LBS	CRYOGEN H_2/O_2
5,000 LBS	TANK (INCLUDING PUMPS AND INSULATION)
10,000 LBS	AIRBORNE SUPPORT EQUIPMENT
65,000 LBS	TOTAL

  - MAY BE USED TO "BALLAST OUT" PAYLOADS WHICH ARE LESS THAN 28' LONG AND 50,000 LBS
  - THE BALLAST (I.E., THE CRYOGEN) ALSO SERVES TO CONTROL C.G. LOCATION
  - OTM MAY RECEIVE RECOVERABLE ET FUEL

PRECEDING PAGE BLANK NOT FILMED

GROUND OPERATIONS

We have assumed a proto-flight approach for all but one SS module. A selected habitable module type (probably the SHM) would have an engineering model or prototype which would be used on the ground for interface verification and training. There would be no general hi-fidelity complete SS facility on the ground.

Existing facilities at KSC are committed to Spacelab and VAFB lacks suitable facilities for Space Station processing. A trade study indicated that a CITE-type simulator offers a good balance of capabilities and cost.

There will be a reduction in test requirements as confidence is gained in the hardware. For example, crew members may have audio-visual instructions projected inside their helmets to assist them in parts replacement.

SPACE STATION GROUND LAUNCH AND LOGISTICS OPERATIONS

- PROTO-FLIGHT CONCEPT ASSUMED
- NO (GENERAL) HI-FIDELITY SS ON GROUND
- DEDICATED SS GROUND PROCESSING FACILITIES ARE NEEDED
- A SIMULATOR/EMULATOR SHOULD BE DESIGNED TO TEST AND VERIFY INTERFACES
- REFLIGHTS WILL REQUIRE LESS GROUND TESTING THAN INITIAL FLIGHTS
- GROUND-BASED TRAINING AND LOGISTICS PROGRAMS HAVE SPACE-BASED APPLICATIONS

ESSENTIAL DEDICATED FACILITIES

After reviewing existing facilities at KSC and VAFB, it was determined that they are either unsuitable for Space Station ground operations or committed to other programs. New facilities, designed and equipped for Space Station processing, are not only necessary but are also more efficient.

ESSENTIAL DEDICATED FACILITIES

	KSC	VAFB
HIGH BAY SPACE	20,000 SQ. FT.	12,000 SQ. FT.
- CHECK-OUT STANDS AND GSE	4	2
- 2-HOOK BRIDGE CRANE	80,000 LB.	50,000 LB.
- 30-FOOT ROLL-UP DOOR	✓	✓
- CLASS 100,000 CLEAN	✓	✓
SUPPORT AND OFFICE SPACE	30,000 SQ. FT.	12,000 SQ. FT.
- SIMULATOR	✓	✓
- LOGISTICS SPACE	(10,000 SQ. FT.)	(6,000 SQ. FT.)

SPACE STATION INTERFACE VERIFICATION, TEST, AND TRAINING OPTIONS

The recommended approach combines mechanical and functional verification and tests with a computer simulation of Space Station operating conditions. Our simulator concept uses ground hardware rather than flight hardware because of the great difference in cost.

SPACE STATION INTERFACE VERIFICATION, TEST, AND TRAINING OPTIONS

OPTION	ADVANTAGES	DISADVANTAGES
1. HIGH-FIDELITY MODEL USING FLIGHT-LIKE HARDWARE	1. MAXIMUM ASSURANCE OF FORM, FIT, AND FUNCTION COMPATIBILITY 2. ACCOMMODATES MOST OF THE FUNCTIONAL GSE REQUIREMENTS 3. MOST USABLE FOR TRAINING	1. HIGH ACQUISITION COST 2. HIGH MAINTENANCE/OPERATION COST, DEDICATED FACILITY AND PERSONNEL (e.g., SAIL) 3. STILL REQUIRES ADDITIONAL TRAINING EQUIPMENT (e.g., WEF MODELS)
2. SIMULATOR CITE-TYPE MECHAN-ICAL AND FUNCTIONAL INTERFACES	1. FAMILIAR CONCEPT TO IMPLEMENT AND OPERATE (CITE EXPERIENCE) 2. LESS COSTLY TO IMPLEMENT AND OPERATE THAN OPTION 1	1. LIMITED USABILITY FOR TRAINING
3. ANALYTICAL VERIFICATION WITH MINIMUM INTERFACE DEMONSTRATION	1. LOWEST COST OPTION 2. PLACES INTERFACE COMPATIBIL-ITY RESPONSIBILITY ON HARDWARE SUPPLIER 3. SHORTEST GROUND PROCESSING TIME	1. HIGHEST RISK OF INCOMPAT-IBILITY DUE TO MINIMUM TEST/ DEMONSTRATION 2. NOT USABLE FOR TRAINING

LAUNCH SITE TEST REDUCTION

These major tests were considered in arriving at the "initial" and "reflight" numbers on the chart opposite.

- Post-ship functional
- Orbiter integration (CITE)
- Space station integration (simulator)
- Space station functional compatibility
- End-to-end (closed loop)
- Mission simulation

These reflights will require less testing than the initial flights.

LAUNCH SITE TEST REDUCTION

ELEMENTS TESTED	INITIAL*	REFLIGHTS*
SPACE STATION MODULES	5	2
LOGISTICS MODULES	4	1
PAYLOADS		
ATTACHED	2.5	.5
FREE-FLYING	1.5	.2
REPLACEMENT HARDWARE	2	0

*AVERAGE NUMBER OF MAJOR TESTS.

LOGISTICS AND TRAINING CONSIDERATIONS

Planning for logistics support and training activities must accommodate the unique requirements of ground and space operations. In addition, there are several requirements which are present in both environments. These include:

- Safety
- Automation
- Standardized interfaces
- Security (DoD missions)

LOGISTICS AND TRAINING CONSIDERATIONS

	GROUND	SPACE
DOCUMENTATION	MANUALS/PROCEDURES	HEADS-UP DISPLAYS
MAINTENANCE AND REPAIR	AMBIENT ENVIRONMENT	SPACE SUIT FATIGUE
REPLACEMENT	ADEQUATE INVENTORY	LIMITED SPARES
ASSEMBLY	GSE	FSE (RMS & MMU)
TEST/CALIBRATION	SIMULATOR	BITE/RF LINK
CONTINGENCY	INCONVENIENCE	LIFE-THREATENING

GROUND SEGMENT CHARACTERISTICS

In the Space Station/Space Platform evolution the Ground Segment must provide support to multiple Space Platforms and Space Stations. The Ground Segment is developed by building upon the architectures of the earlier Space Transportation System, Space Platform and Space Station scenarios. Each element in the Space Station/Space Platform evolution is developed as required and the element interfaces remain unchanged with the evolution. The ground security needs must be built in from the beginning.

The acronyms on the chart are:

- DHS - Data Handling Facility
- SSCC - Space Station Control Center
- SPCC - Space Platform Control Center
- NASCOM - NASA Communications Network
- CSOC - Consolidated Space Operating Center

GROUND SEGMENT CHARACTERISTICS

- EVOLUTIONARY DESIGN
  - UNCHANGING INTERFACES FOR EVOLUTIONARY GROWTH
  - MODULAR AND FLEXIBLE ARCHITECTURE
  - STANDARDIZED USER INTERFACES FOR NASA AND DoD PAYLOADS
  - SIMILAR BUT SEPARATE ARCHITECTURES FOR SPACE STATION AND SPACE STATION CONTROL CENTERS
- CENTRALIZED CONTROL AND COMMUNICATIONS FUNCTIONS
  - DHF ROUTES ALL TELEMETRY DATA TO THE USERS AND TRANSMITS ALL COMMAND DATA TO TDRSS/NASCOM
  - SSCC CONTROLS ALL SPACE STATION ACTIVITIES
  - SPCC CONTROLS ALL SPACE PLATFORM ACTIVITIES
- UTILIZES EXISTING AND PLANNED NASA AND DoD FACILITIES
  - TDRSS/NASCOM USED FOR ALL UPLINKS AND DOWNLINKS
  - SHUTTLE GROUND SUPPORT FACILITIES (JSC AND CSOC) USED DURING PRE-DEPLOYMENT ACTIVITIES
- JOINT NASA/DoD GROUND SEGMENT ARCHITECTURE
  - SECURITY BUILT INTO GROUND SEGMENT EARLY IN THE DESIGN PHASE
  - COMPATIBLE WITH THE NATIONAL SPACE OPERATIONS NETWORK

GROUND SEGMENT MISSION CONTROL FUNCTIONS

The next three charts list the functions required of the growth segment relative to mission control, system support, and mission support. The degree to which (as a function of time) these functions are performed in the SS or on the ground is a major trade. It appears desirable to gradually grant increasing autonomy to the SS, thus reducing ground crew size. It also appears reasonable, for the same reason, to increasingly automate the ground operations. A heavily automated ground station may still be an appropriate choice over performing the same functions (automatically) in the SS. This might be decided by the cost effectiveness of computers on the ground vs. computers in space.

GROUND SEGMENT MISSION CONTROL FUNCTIONS

- TRACKING, TELEMETRY AND COMMANDING
- ORBITAL NAVIGATION AND MANEUVERING
- SPACE SEGMENT STATUSING, ANALYSIS, AND CONTROL
- GROUND SEGMENT STATUSING, ANALYSIS, AND CONTROL
- CONTROL AND DISPLAY
- TIME DISTRIBUTION AND CONTROL
- SYSTEM INITIALIZATION AND RECOVERY

ALL FUNCTIONS SHARED WITH SPACE STATION

GROUND SEGMENT SYSTEM SUPPORT FUNCTIONS

- COMMUNICATIONS
- SITE SERVICES
- SYSTEM DEVELOPMENT
- CONFIGURATION MANAGEMENT
- INTEGRATED LOGISTICS SUPPORT
- SECURITY SYSTEMS
- ADMINISTRATIVE SERVICES

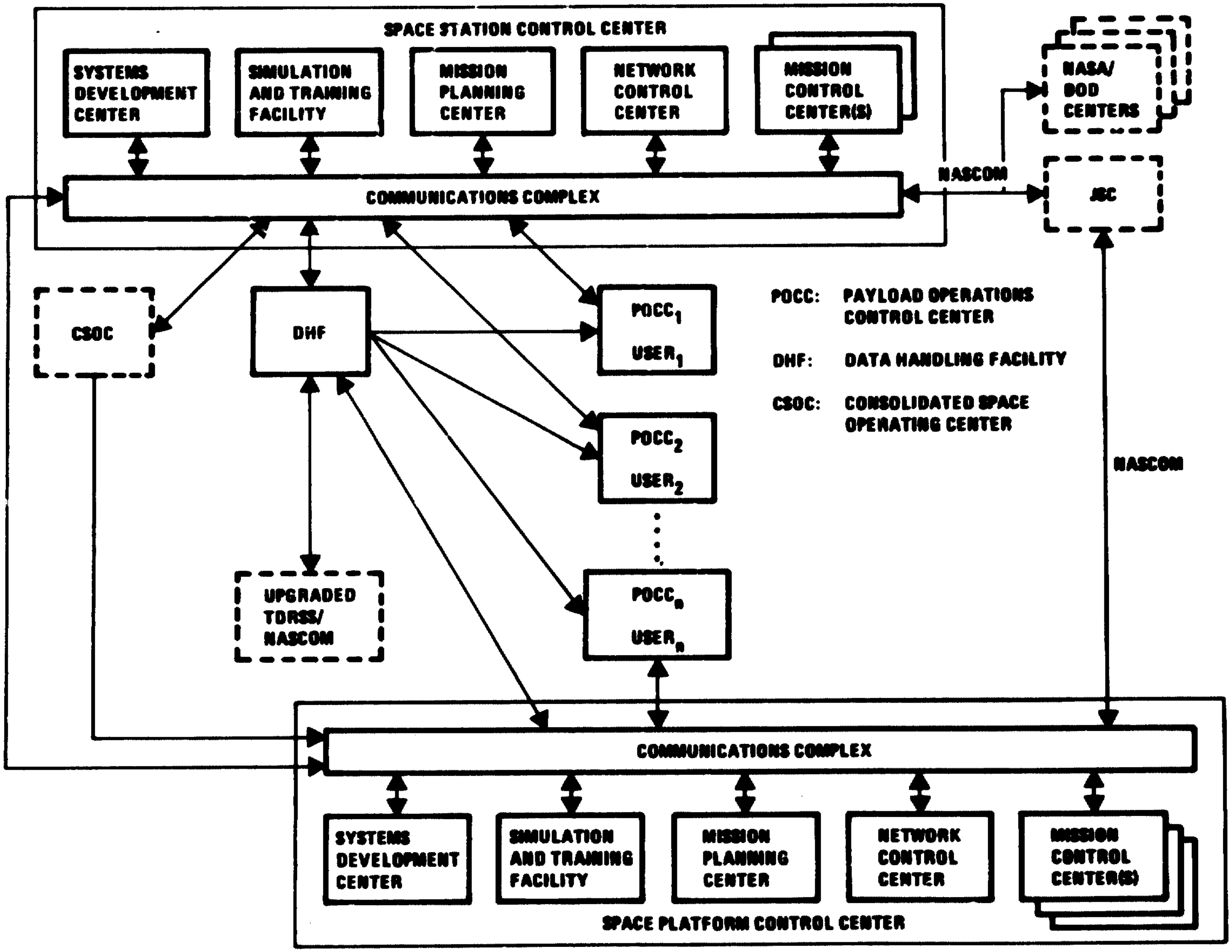
GROUND SEGMENT MISSION SUPPORT

- MISSION PLANNING
- SPACE SEGMENT DATA PREPARATION
- GROUND SEGMENT DATA PREPARATION
- TRAINING
- REHEARSALS
- PERFORMANCE ANALYSIS

The number of users and the downlink data requirements dramatically increase for scenarios including either Space Stations or Space Platforms. The Ground Segment must now support "N" number of users. This increased telemetry load is expected to exceed the near-term TDRSS/NASCOM capabilities, and an upgraded TDRSS/NASCOM will be required. TDRSS/NASCOM and SS/SP resource allocations will require centralized mission planning, and command and control. Each SS or SP will require a dedicated Mission Control Center portion to perform the command and control function. Mission planning and TDRSS/NASCOM and SS/SP resource allocation functions have been centralized in the Mission Planning Center. A Network Control Center will be required to control, monitor and allocate the SS/SP Ground Segment resources. SS/SP and Ground Segment network simulations become critical activities for performance prediction, training, and test verification. A Simulation and Training Facility will be required to perform these activities. Since Ground Segment evolutionary development will be an on-going activity during operations, a dedicated Systems Development Center will be required to support these efforts.

The key element that is added to the Ground Segment in the Space Station scenario is the Space Station Control Center (SSCC) or Space Platform Control Center (SPCC). It centralizes in one facility the Systems Development Center, Simulation and Training Facility, Mission Planning Center, Network Control Center and Mission Control Center(s). The SSCC/SPCC also provides a communications complex for internal and external communication. For scenarios where both Space Stations and Space Platforms are present the Ground Segments may be combined to some extent, saving duplication of facilities.

BASELINE SPACE STATION GROUND SEGMENT



POCC: PAYLOAD OPERATIONS CONTROL CENTER

DHF: DATA HANDLING FACILITY

CSOC: CONSOLIDATED SPACE OPERATING CENTER

ORIGINAL PAGE IS OF POOR QUALITY

SPACE STATION GROUND SEGMENT CHARACTERISTICS/ASSUMPTIONS

The ground segment control center(s) concept is based on TRW's previous work on the Space Platform. It is assumed there will be joint NASA/DoD control centers. The centers must allow for evolutionary growth, including changes in the autonomy and automation of both space and ground segments. In particular, it is anticipated that automation will increase both in space and on the ground, and that the Space Station will become increasingly more autonomous, relative to ground control.

The STS control is assumed to remain with existing facilities. The use of TDRSS and existing TDRSS ground facilities are assumed.

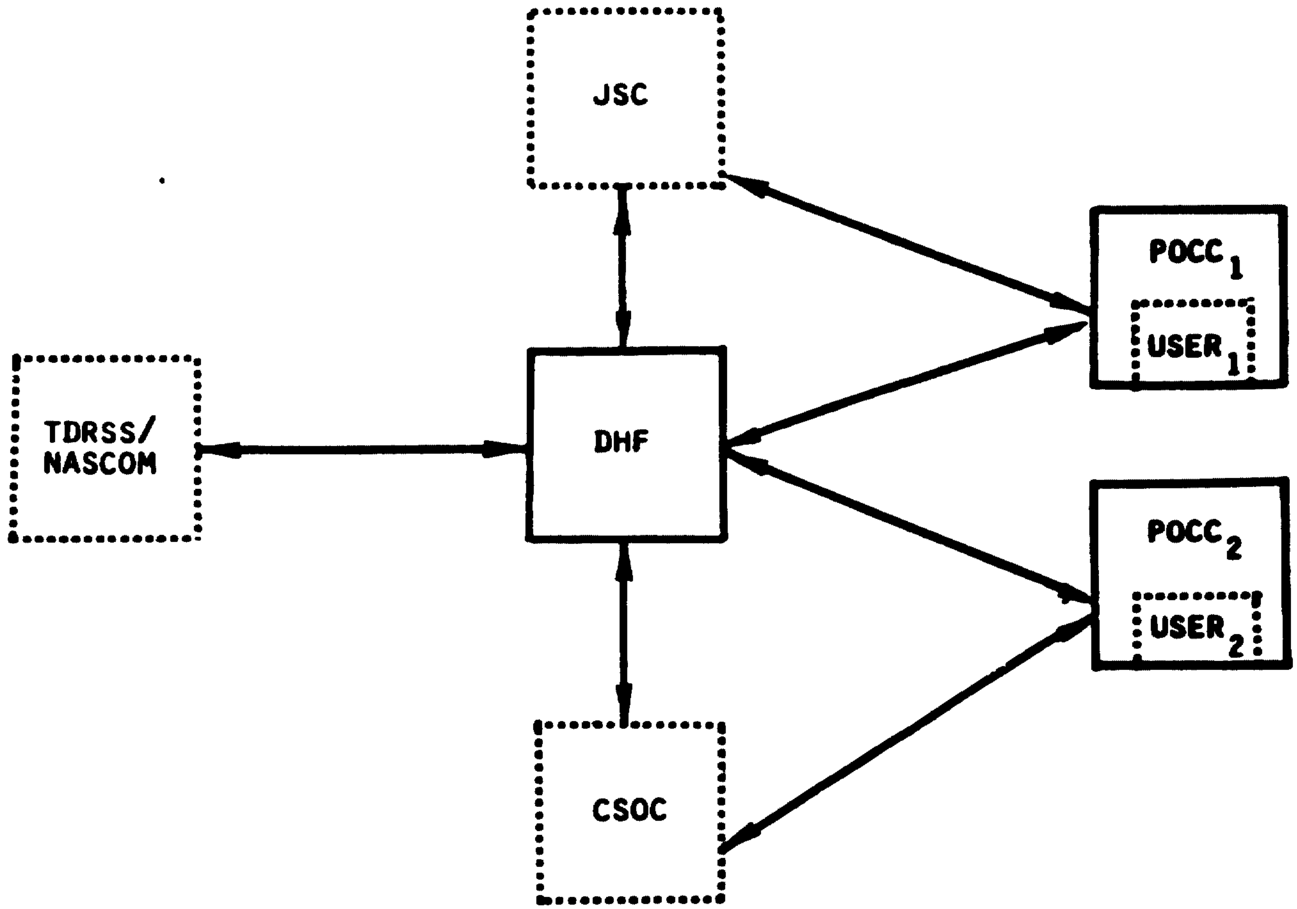
SPACE STATION GROUND SEGMENT CHARACTERISTICS/ASSUMPTIONS

- JOINT NASA/DOD CONTROL CENTER(S) FOR SPACE STATION
- GROUND SEGMENT INTERFACES BASED ON SPACE PLATFORM SEGMENT DESIGN WORK
- EVOLUTIONARY CONCEPTS MAINTAIN STANDARD (UNCHANGING) INTERFACES
- SHUTTLE OPERATIONS CONTROL REMAINS WITH EXISTING/PLANNED NASA AND DOD CENTERS
- DATA HANDLING FACILITY CONCEPT EMPHASIZES EFFICIENT USE OF COMMUNICATIONS RESOURCES
- TDRSS REDUCES NEED FOR ADDITIONAL GROUND STATIONS TO SUPPORT SPACE STATION TT&C ACTIVITIES
- SIMILAR BUT SEPARATE ARCHITECTURES FOR SPACE PLATFORM AND SPACE STATION CONTROL CENTERS, EXCEPT FOR ADDED FUNCTIONS DUE TO MANNED ACTIVITIES ON SPACE STATION

SPACE TRANSPORTATION SYSTEM EVOLUTIONARY SCENARIO GROUND SEGMENT

The initial phase of an evolving Space Station Ground Segment design is one that supports early NASA and DoD Shuttle/Spacelab users. During this phase, the ground segment would consist of a Data Handling Facility (DHF) and one or more Payload Operations Control Centers (POCCs). The data processing functions of the ground segment have been modularly allocated to the DHF and POCCs. The DHF provides a "bent pipe" routing of telemetry data to the POCCs. The POCCs provide standard interface equipment (i.e., terminals and communications equipment) to allow NASA and DoD user(s) interface with the DHF. User generated payload commands would be generated at the POCCs and routed to the DHF for transmission to the TDRSS/NASCOM network. This would provide virtually direct payload command operation. The POCCs would have a minimal interface with JSC and the CSOC; one that exchanges payload and Shuttle/Spacelab status data. This initial phase allows for an evolutionary integration of these facilities with the facilities that will be required for the Space Station and Space Platform. The interfaces of the DHF and POCCs will be unchanging with the evolutionary scenarios.

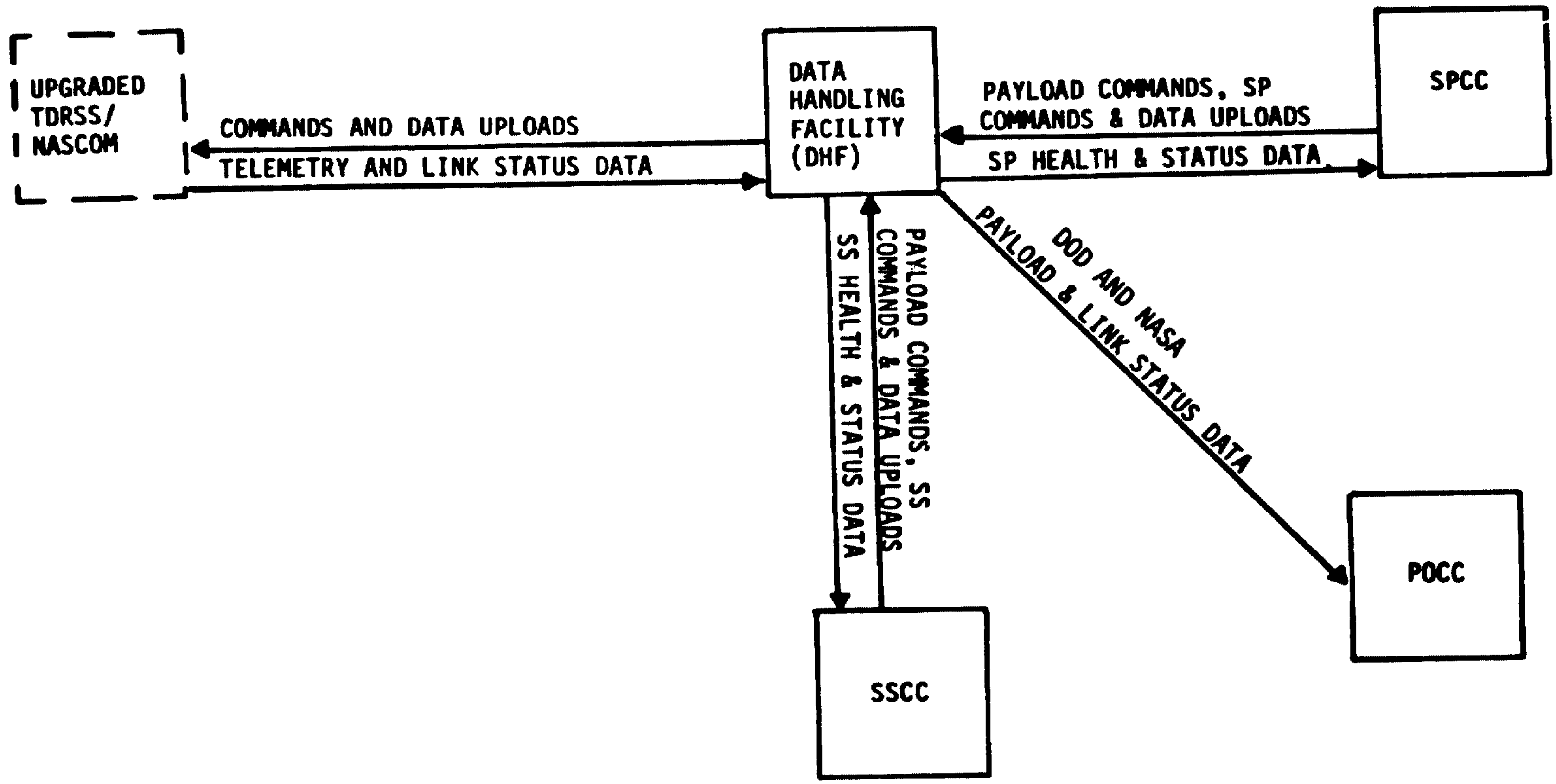
SPACE TRANSPORTATION SYSTEM EVOLUTIONARY SCENARIO GROUND SEGMENT



DATA HANDLING FACILITY INTERFACES

The Data Handling Facility (DHF) is the telemetry and command data interface with the TDRSS/NASCOM Network. All Space Station, Space Platform and Payload telemetry data is routed to the DHF via TDRSS/NASCOM. The DHF deframes the telemetry data and routes it to the appropriate user facility, i.e., SSCC, SPCC, or POCC. The DHF also receives TDRSS/NASCOM link status data and routes the status data to the user facilities. Space Station, Space Platform and Payload commands and data uploads are sent to the DHF where they are integrated, framed and transmitted to the TDRSS/NASCOM network.

DATA HANDLING FACILITY INTERFACES

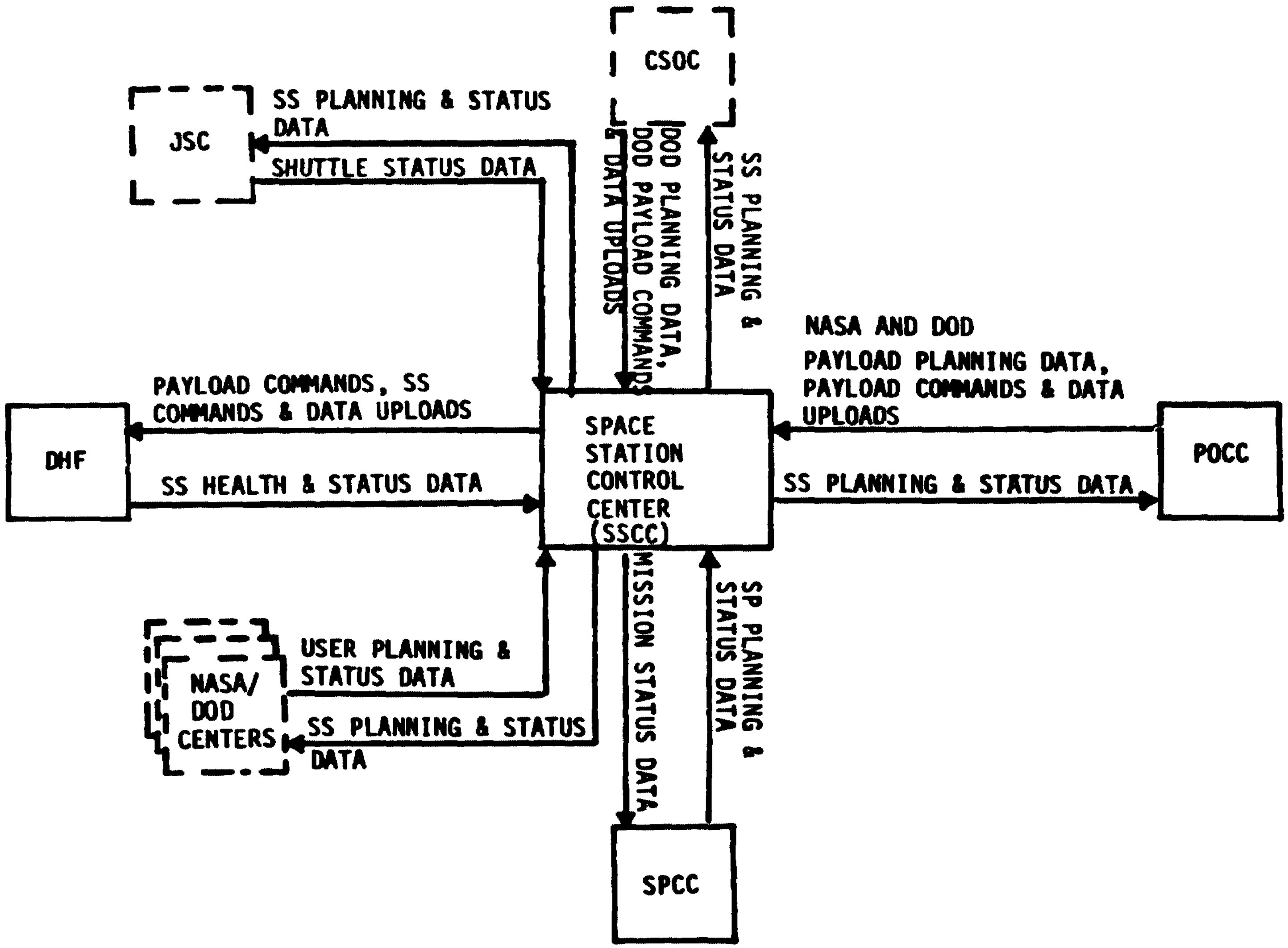


ORIGINAL PAGE IS OF POOR QUALITY

SPACE STATION CONTROL CENTER INTERFACES

The Space Station Control Center (SSCC) is the facility that integrates Space Station (SS) payload commands and data uploads, and routes them to the DHF for transmission to the TDRSS/NASCOM network. Payload commands and data uploads are sent to the SSCC by one or more POCCs for NASA payloads and DoD payloads. The SSCC also transmits Space Station commands and data uploads to the DHF for transmission to the TDRSS/NASCOM network. Space Station health and status data and TDRSS/NASCOM link status data are received from the DHF. The SSCC transmits Space Station planning and status data to NASA and DoD users for use in payload mission planning and Space Station performance monitoring.

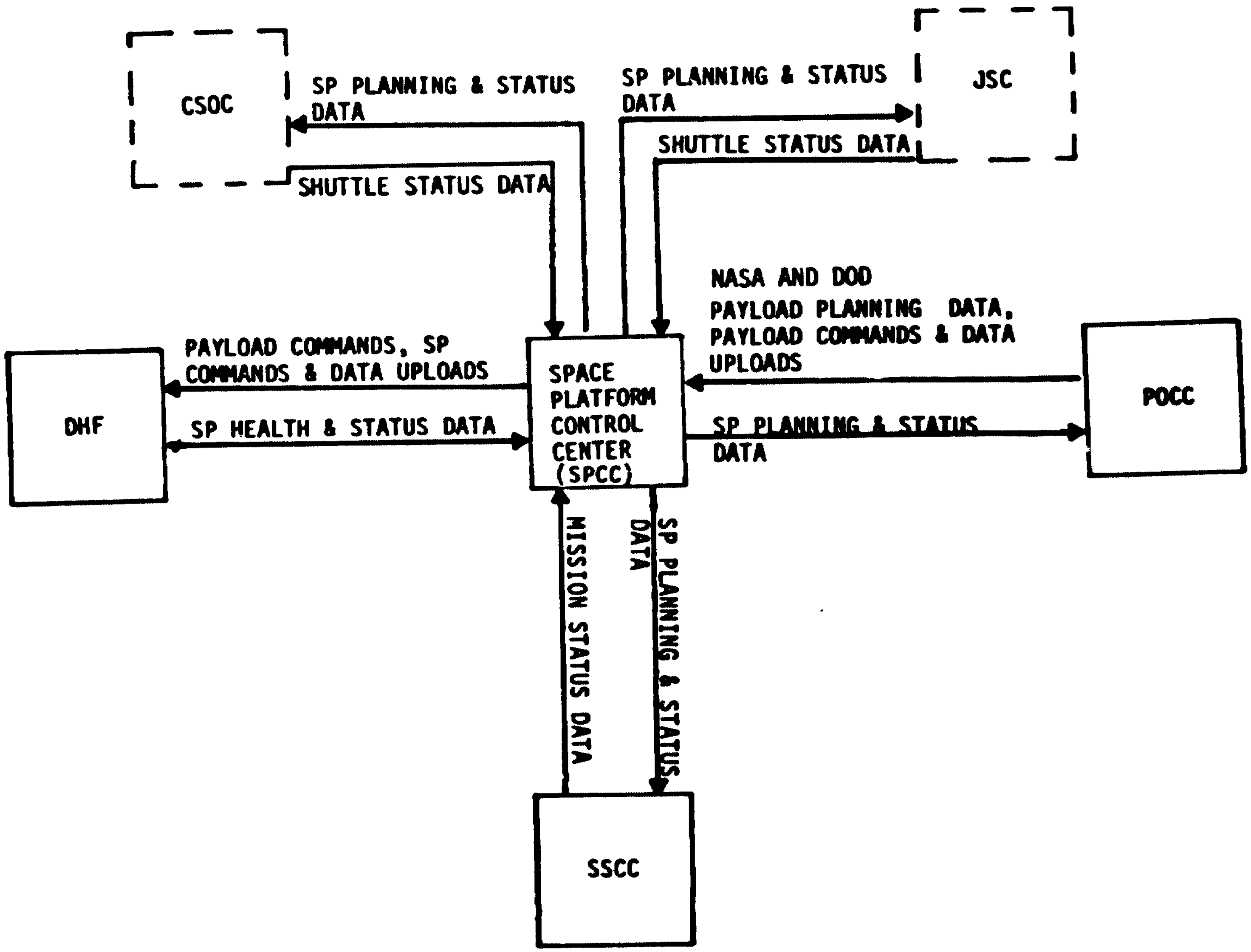
SPACE STATION CONTROL CENTER INTERFACES



SPACE PLATFORM CONTROL CENTER INTERFACES

The Space Platform Control Center (SPCC) is the facility that integrates Space Platform (SP) payload commands and data uploads, and routes them to the DHF for transmission to the TDRSS/NASCOM network. Payload commands and data uploads are sent to the SPCC by one or more POCCs for NASA payloads and DoD payloads. The SPCC also transmits Space Platform commands and data uploads to the DHF for transmission to the TDRSS/NASCOM network. Space Platform health and status data and TDRSS/NASCOM link status data are received from the DHF. The SPCC transmits Space Platform planning and status data to NASA and DoD users for use in payload mission planning and Space Platform performance monitoring.

SPACE PLATFORM CONTROL CENTER INTERFACES

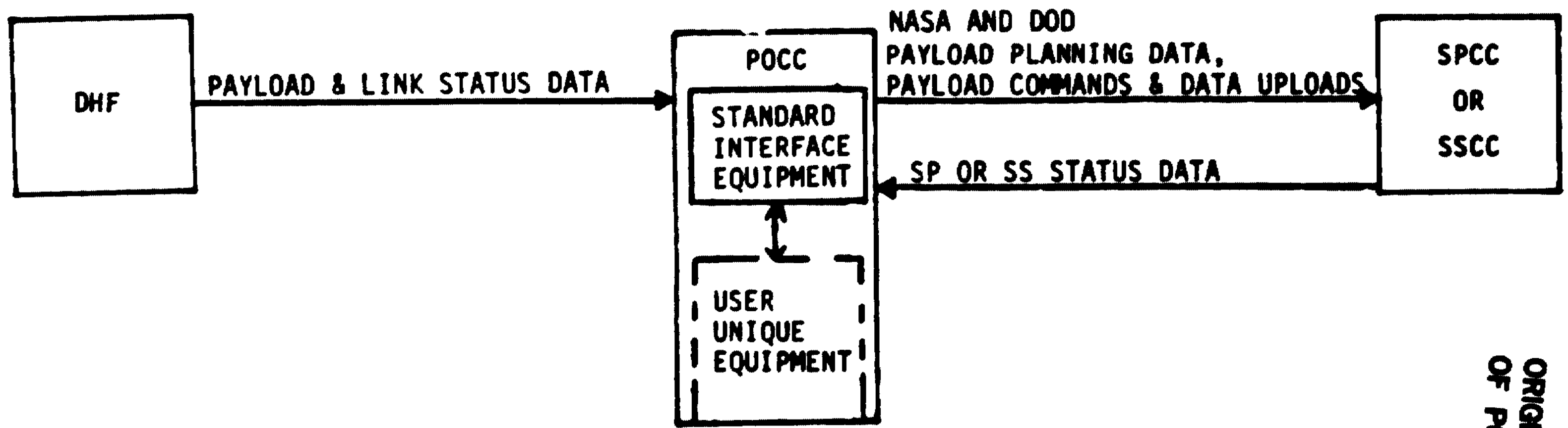


ORIGINAL PAGE IS OF POOR QUALITY

PAYLOAD OPERATIONS CONTROL CENTER INTERFACES

The Payload Operations Control Center (POCC) is the facility that directly interfaces with the payload user(s). The POCC consists of standard interface equipment (i.e., terminals and communications equipment) that provide the NASA and DoD user(s) a standard interface with the Space Station Ground Segment. The POCC receives payload telemetry data and TDRSS/NASCOM link status from the DHF. User commands and data uploads are routed through the standard interface equipment to the Space Platform Control Center (SPCC) or Space Station Control Center (SSCC). The POCC receives Space Platform status from the SPCC or Space Station status from the SSCC.

PAYLOAD OPERATIONS CONTROL CENTER INTERFACES



ORIGINAL PAGE IS
OF POOR QUALITY

OTHER TOPICS

GEO SPACE STATION

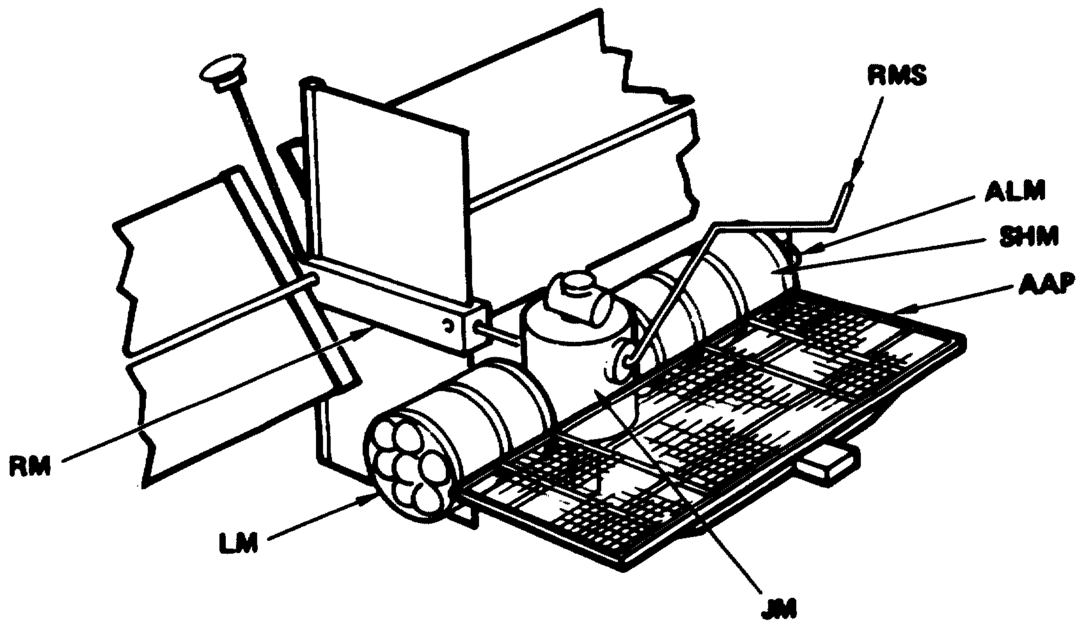
A permanent Space Station at geosynchronous orbit offers some advantages for servicing satellites. During the period 1990-2000 there are in excess of 300 launches planned for GEO or near-GEO.

A Space Station of the same size and configuration as the initial PEO SS is reasonable. It has accommodation for a crew of three, sufficient facilities for servicing/repairing satellites (RMS, airlock module, assembly area platform) and is the base for a TMS, all without requiring excessive weight in GEO.

A trade between assembling the SS in LEO vs assembling in GEO shows a slight advantage in cost/weight for the LEO assembly. This is in addition to the practical benefits of assembly and checkout of a complete system before committing it to GEO.

Resupply and crew changeout is assumed to be on a 90 day cycle. A Logistics Module about 15' long x 14' dia. would carry supplies for a crew of three for 90 days plus accommodating life support and the replacement crew. The weight of such a module including supplies and crew would be approximately 21,000 lbs. It would be transferred by an ROTV.

GEO SPACE STATION



- SIMILAR TO PEO SS
- CREW, 3
- POWER, 30 kW NET
- WEIGHT 110,000 LBS, INCLUDING LOADED LM
- ASSEMBLE IN LEO, BOOST TO GEO USING ROTV WITH EXTRA FUEL TANKS
- BASE FOR GEO TMS
- RESUPPLY, CREW CHANGEOUT, 90 DAYS
- LM MODIFIED TO TRANSPORT SUPPLIES AND CREW

BERTHING PORT CONSIDERATIONS

For ease of assembling the SS in space and to permit re-arrangement of the SS architecture, a standard androgynous interface is required. Also, it is desirable that during assembly the interface be capable of accepting modules approaching each other with linear and angular misalignment. The interface should mate and lockup automatically to provide the structural and atmospheric integrity required, and be capable of verification either by visual inspection or by instrumentation.

A berthing interface with some of the same features may be employed where crew passage is not required. A typical example is payload mounting where payloads are to be attached to the exterior of the SS by using the manipulator system.

BERTHING PORT CONSIDERATIONS

ALL MANNED MODULES SHALL BE INTERCONNECTED USING A SINGLE DESIGN FOR A BERTHING PORT. THIS STANDARD PORT SHALL HAVE THE FOLLOWING FEATURES:

- 30-INCH DIAMETER PASSAGE FOR CREW AND EQUIPMENT
- PRESSURE TIGHT DOOR
- 90-DEGREE INDEXED ANDROGYNOUS INTERFACE
- STANDARD POWER, SIGNAL AND DATA INTERFACES
- SUITABLE MISALIGNMENT PROVISIONS, BOTH PRE-AND POST-MATING
- PROVIDES BERTHING ONLY - NOT DOCKING

A SMALLER BERTHING MECHANISM USED WHERE CREW PASSAGE IS NOT REQUIRED. (SAME AS ON SPACE PLATFORM)

CONTROLLED DEBOOST FOR SS

At some time in the future when the SS has outlived its usefulness it will be necessary to dispose of it. The most probable disposition will be to deboost it into the ocean after removing any undesirable contaminants. This chart presents some considerations of the deboost method.

CONTROLLED DEBOOST FOR SS

- PROVIDE SOLID RETROROCKETS ON SS FOR EVENTUAL DEBOOST
- DEBOOST INTO LARGE SAFE AREA (INDIAN OCEAN)
- ALLOW DECAY TO 90 NMI (DECAYING ABOUT 1.5 NMI/ORBIT)
- FIRE RETROROCKETS OF 100 FT/SEC

- INITIAL SS	1800 LB
- INTERIM SS	3300 LB
- GROWTH SS	7300 LB

(ASSUMED I_{SP} = 250 SEC)

- ΔV IS EQUIVALENT TO LOSS OF 30 NMI

ORBITER TRANSFER VEHICLE CONCLUSIONS

It is planned to use expendable OTV's at the beginning of the program and to switch to reusable OTV's when a LEO SS becomes operational. Reusable OTV's are cost-effective in several ways:

- Saves the expense of a new OTV for each mission
- Structurally lighter
- Saves fuel
- Payloads in HEO can be recovered
- Aerobraking (probably fixed type instead of ballute) can be used effectively to reduce fuel
- Saves the cost of lifting an OTV to LEO for each mission
- OTV fuel can often be lifted to LEO SS storage as "make up ballast" for small payloads in the Orbiter

ORBITAL TRANSFER VEHICLE CONCLUSIONS

- AN OTV IS A VITAL PART OF THE ARCHITECTURE OF ALL SCENARIOS
- AN EXPENDABLE OTV IS THE INITIAL CHOICE
- A PERIGEE-ONLY OTV IS NOT COMPETITIVE
- REUSABLE OTV'S ARE COST EFFECTIVE ONCE AN SS IS OPERATIONAL
- REUSEABLE OTV'S CAN BE MADE LIGHTER AND LESS EXPENSIVE SINCE THEY NEED NOT CONTAIN FUEL DURING ORBITER TRANSPORT
- AEROBRAKING IS ADVANTAGEOUS FOR REUSEABLE OTV'S (ROTV'S)
- USE OF THE TMS WITH THE ROTV ALLOWS PAYLOAD RECOVERY AND IS COST EFFECTIVE
- THE ROTV TANKAGE SHOULD BE MODULAR TO ACCOMMODATE VARYING PAYLOAD WEIGHT
- COST TRADE CONSIDERATIONS:
  - OTV PROPELLANT MASS FRACTION ASSUMPTIONS ARE CRITICAL
  - STS TRANSPORTATION COSTS DOMINATE
  - PAYLOAD SIZE HAS LITTLE EFFECT ON RELATIVE COSTS

SS TETHER APPLICATIONS

A number of possible applications of tethering to the SS were studied. The evaluation of their potential is indicated, as applied to the interim period (1995) or later. For the initial SS, probably only the satellite tethering might be used, depending on STS experiments in the late 1980's.

The most attractive future possibility is a combination of two tethers, one inward and one outward. One would tether a single satellite and include antennas and other communications capability. The other would be used for a combination of power generation, orbit maintenance and energy storage; all as augmentations to other capabilities. These functions would be accomplished individually to handle peaking of SS needs.

SS TETHER APPLICATIONS

APPLICATION	POTENTIAL	COMMENTS
TETHER SATELLITES	HIGH	PLANNED STS EXPERIMENTS
TRANSFER TETHER (ELEVATOR)	LOW	STS BENEFIT APPEARS LIMITED
ORBIT TRANSFER	MODERATE	RELEASE OF TETHERED SPACECRAFT
STABILIZATION	MODERATE	INCLUDES DAMPING AND LIMITED POINTING
ARTIFICIAL GRAVITY	MODERATE	NO SPECIFIC NEED AT PRESENT
POWER GENERATION	HIGH	SUPPLEMENT SOLAR ARRAYS
ORBIT MAINTENANCE	MODERATE	ATTRACTIVE COMBINED WITH GENERATOR
ENERGY STORAGE	MODERATE	ATTRACTIVE COMBINED WITH GENERATOR
ANTENNAS	HIGH	COMMUNICATIONS AND RADIO ASTRONOMY
STRUCTURES APPLICATIONS	MODERATE	NO SPECIFIC NEED AT PRESENT

ARTIFICIAL GRAVITY

Of all the known means of producing artificial gravity, none are completely successful in fulfilling the requirements of a SS. Indeed, the requirements themselves are but vaguely defined.

Rotating a centrifuge inside a module has the restriction of limited size, and a gravity field which varies from zero at the center of the centrifuge to a maximum at the outer radius. For even a small, one-man centrifuge, the weight is high and the angular momentum generated by the centrifuge has to be compensated by momentum wheels. If the centrifuge is external to the HM, there is the problem of a rotating joint, or airlock plus the required life support systems.

Rotating a complete module compounds some of these problems but has the advantage of providing a space large enough for work and living. The junctions between the rotating module and the remainder of the SS present an unsolved design problem.

The rotation of the complete SS presupposes a SS architecture completely different from that which is proposed. Angular momentum accommodation, solar and payload pointing are all drastically affected.

Creation of artificial gravity by adding orbital ΔV to produce centrifugal force and balancing it by continuous thruster firing uses excessive amounts of fuel for very low gravity fields.

Tethering modules to produce an out-of-balance condition between orbital velocity vs. orbital radius, and consequently centrifugal force vs local gravity has not been demonstrated. Again it supposes a SS of a completely different type.

ARTIFICIAL GRAVITY

- POSSIBLE MEANS OF PRODUCING ARTIFICAL GRAVITY:
  - CENTRIFUGE INTERNAL TO A MODULE
  - ROTATION OF MODULE(S) ABOUT OWN CENTERLINE(S)
  - ROTATE ENTIRE SPACE STATION
  - CONTINUOUSLY FIRE THRUSTERS
  - MODULES SEPARATED BY TETHER

- CONSIDERATIONS:
  - LOW GRAVITY PRODUCED
  - NON-UNIFORMITY OF GRAVITY OVER MODULE
  - ROTATING CONNECTIONS
  - ANGULAR MOMENTUM EFFECTS
  - HIGH FUEL CONSUMPTION
  - EXTREME DISTANCES FOR TETHERS
  - SOLAR POINTING FOR PART OF SS
  - PAYLOAD POINTING
  - PSYCHOLOGICAL EFFECTS OF SPINNING
  - COST

SS ATTITUDE CONTROL

The SS could be pointed precisely only with extreme difficulty and great cost of momentum storage and unloading means. The number of sensors and actuators and the stiffness and weight of the structure would require a great increase. Additionally, future pointing requirements would be unknown. It appears better to nominally point the SS, sufficient for solar/thermal reasons and to minimize torques and to independently gimbal those payloads requiring better or different pointing.

We have assumed stellar/inertial sensors, control moment gyros (of the Skylab class, or larger) and both magnetic and propulsive unloading of momentum. The unloading should always be done at times and in directions so as to contribute to altitude maintenance.

SS ATTITUDE CONTROL

- ATTITUDE CONTROL OF THE SS BODY TO WITHIN ± 1-2 DEGREES IS POSSIBLE
- PAYLOADS HAVING PRECISE POINTING REQUIREMENTS ARE GIMBALLED
- STELLAR/INERTIAL SENSORS ARE ASSUMED
- CONTROL MOMENT GYROS CMG'S ARE USED TO ABSORB:
  - CYCLIC MOMENTUM
  - SHORT-TERM SECULAR MOMENTUM
- MOMENTUM UNLOADING:
  - MAGNETIC TORQUERS
  - PROPULSION (COMBINED WITH REBOOST)
- SIZING ESTIMATES:
  - 3 TO 6 SKYLAB SIZE (3100 N-M-SEC) CMG'S ARE ADEQUATE
  - MOMENTUM UNLOADING PROPELLANT IS ABOUT ONE-TENTH OF ALTITUDE MAINTENANCE PROPELLANT (FOR BALANCED CONFIGURATIONS)

DISTURBANCE TORQUE ACCOMMODATION

Our studies have shown that it should be possible to choose an SS configuration and an orientation that minimizes net torques by balancing aerodynamic and gravity gradient effects. This is particularly true if an operating altitude is chosen where the effects are approximately equal. That altitude will change with SS size and time in the solar cycle.

Areas (sails) and masses might be used to provide controllable moments of inertia and center of pressure to accommodate SS variations, both in configuration and dynamically (crew, RMS, etc. motion). The torques are extremely sensitive to a balanced SS configuration.

Several orientation/configuration combinations were examined, with none having all desirable attributes. Our tentative choice would have the long axis of the SS body (the AAP end) earth pointing, the velocity vector in the plane of the body modules, and other rotations allowing the sun to be perpendicular to the solar arrays and parallel to the resource module radiators. Unfortunately, for many orbits, this requires two (up to 90°) turns per orbit about the earth-pointing axis.

DISTURBANCE TORQUE ACCOMMODATION

- DISTURBANCE TORQUES ARE:
  - AERODYNAMIC - DEPENDENT ON:
    - SOLAR CYCLE
    - ALTITUDE
    - CP/CG RELATIONSHIP
    - ORIENTATION W.R.T. VELOCITY VECTOR
  - GRAVITY GRADIENT - DEPENDENT ON:
    - MOMENTS OF INERTIA
    - ORIENTATION W.R.T. LOCAL VERTICAL
- AERODYNAMIC TORQUES PREDOMINATE AT LOWER ALTITUDES (< 200 NM!)
- TORQUES CREATE SECULAR AND CYCLIC ANGULAR MOMENTUM WHICH MUST BE STORED AND UNLOADED
- TORQUES ARE VERY CONFIGURATION SENSITIVE (E.G., CHANGES OF 1 METER MAY DOUBLE TORQUES)
- PREFERRED ORIENTATION IS PROBABLY X-LV, Y-PSL:
    - PRINCIPLE BODY AXIS - LOCAL VERTICAL
    - RESOURCE MODULE AXIS - PERPENDICULAR TO VELOCITY VECTOR
    - ARRAY AXIS - PERPENDICULAR TO SUN LINE

  (DISADVANTAGE - TWICE PER ORBIT X-AXIS TURN)
- CONTROLLABLE SAILS AND MASSES MIGHT BE USED TO MINIMIZE TORQUES WITH
    - CONFIGURATION CHANGES
    - CREW MOVEMENT
    - OTV, P/L, MANIPULATOR MOVEMENT